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ANALYTIC MODELING OF ROCK-STRUCTURE INTERACTION

VOL. 2 USERS GUIDE FOR A COMPUTER PROGRAM

AGBABIAN ASSOCIATES

PREPARED FOR
ADVANCED RESEARCH PROJECTS AGENCY
BUREAU OF MINES

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USERS GUIDE FOR A COMPUTER PROGRAM FOR ANALYTIC MODELING OF ROCK-STRUCTURE INTERACTION

Final Technical Report
Volume 2
April 1973

U. S. BUREAU OF MINES
Contract Number H0220035

Sponsored By
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13 ABSTRACT

This report shows how input is prepared for a computer program for rock-structure interaction. The technical background for the computer program is given in "Analytic Modeling of Rock-Structure Interaction," Final Report by Agbabian Associates to US Bureau of Mines April 1973 under Contract H0220035. The computer program is available in the form of a magnetic tape through National Technical Information Service under the title "Computer Program for Rock-Structure Interaction."

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USERS GUIDE FOR A COMPUTER PROGRAM FOR ANALYTIC MODELING OF ROCK-STRUCTURE INTERACTION

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R-7215-2-2701

FINAL TECHNICAL REPORT

VOLUME 2

ARPA Order Number:	1579, Amendment No. 3
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Name of Contractor:	Agbabian Associates
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Principal Investigator:	Jeremy Isenberg
Phone Number:	(213) 640-0576
Title of Work:	Analytic Modeling of Rock-Structure Interaction. Users Guide for a Computer Program for Analytic Modeling of Rock-Structure Interaction, Volume 2 of 3, Final Report

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Bureau of Mines under Contract No. H0220035.

TECHNICAL REPORT SUMMARY

The objective of this project is to combine a number of recent advances in finite element theory and computer technology for analyzing cavities and structures in rock. This computer program applies to general three-dimensional structures, considers nonlinear material properties, time dependent properties, gravity loading and sequence of excavation or construction.

The final report for this project is in three volumes as follows:

Volume 1 - "Analytical Modeling of Rock - Structure Interaction." Final Report, April 1973.

Volume 2 - "Users Guide for a Computer Program for Analytic Modeling of Rock - Structure Interaction." Final Report, April 1973.

Volume 3 - "Computer Program for Analytic Modeling of Rock - Structure Interaction." Final Report, April 1973.

All three volumes were prepared by Agbabian Associates, under contract H0220035 with U. S. Bureau of Mines. The project was sponsored by ARPA under ARPA Order Number 1579, Amend. No. 3, Program Code 2F10.

During this contract, work has been aimed at producing a user-oriented computer program. The work of writing the program was divided into three areas:

a. Input

b. Execution and output

c. Material properties

The Input Section automatically generates the continuum part of the finite element mesh, including joint elements, allows the user to add other elements (beam, shell, truss) to the mesh, plots the result, reduces the bandwidth and reads loads, material properties, and other quantities necessary to the calculation. The Execution Section forms the global stiffness matrix and solves equations of equilibrium for displacements by an implicit method. The material properties are represented by subroutines within the Execution Section, which are written in a modular form so that if the general equations of nonlinear elasticity, viscoelasticity, viscoplasticity, or plasticity do not suit a particular problem they may be easily modified.

One of the guidelines for this project was to consolidate existing finite element technology into a single, general purpose computer program. Accordingly, the program uses existing finite elements, a proven form of the equation of equilibrium, existing material property descriptions, and an existing bandwidth reducer. However, a small amount of new work was done. A new joint element was developed and an existing concept for automatic mesh generation was greatly extended. Also, a form of Choleski decomposition was modified for efficient use of multibuffering, resulting in substantial improvement in efficiency of solving equations of equilibrium using peripheral storage.

During this study, some new work was reported by other ARPA/Bureau of Mines contractors which has been incorporated in the program. Among these are some creep data obtained by W. A. Wawersik of the University of Utah and strength/deformability data for faults by R. E. Goodman, F. E. Heuze, and Y. Ohnishi of the University of California, Berkeley.

The technical work reported in Volume 1 is divided into two main parts. The first part describes the range of possible application of the computer program to mining engineering problems and reports an extensive analytic study of the Caladay Project hoist room with which experimental data are compared. The second part discusses various aspects of the computer

program and its theoretical basis. Attention is given to the processing of input data and to options available to the user for mesh generation, sequential excavation or construction, automatic bandwidth reduction and plotting of the mesh. Example problems which have been solved during checkout of the program are described.

Volume 2 explains the overall operation of the computer program, defines how input should be submitted to the program, defines the material property models in detail, explains the data stored on each tape and gives flow charts of some subroutines. This input definition is for the version of the program which operates on the UNIVAC 1108. This program is the primary content of Volume 3, and is available on seven track magnetic tape from DDC-TC, U. S. Department of Commerce, Springfield, Virginia 22151, telephone AC (703) 321-8517. The tape is unlabeled, even parity, external BCD and is written at 556 BPI. The tape has constant record sizes, each record being 1920 characters long (24-80 column card images per record). An end of file mark follows the last record on the tape.

Arrangements to obtain copies of Volumes 2 and 3 may also be made through Agbabian Associates, 250 North Nash Street, El Segundo, California 90245, telephone AC (213) 640-0576.

This contract was monitored by Dr. William J. Karwoski, Spokane Mining Research Center, U. S. Bureau of Mines.

FOREWORD

The principal contributors to the computer program described in this report are listed below. All are members of the technical staff of Agbabian Associates.

A. K. Bhaumik

K. P. Chuang

J. M. Clark

K. T. Dill

J. Ghaboussi

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CONTENTS

INTRODUCTION

The main purpose of this document is to show how the input is prepared for the present computer program. The sequence of user operations, logical units required, format for input data and flow charts for some of the frequently-used subroutines are given. There is also a special section on the input for material properties. The prospective user should refer to the final report entitled, "Analytic Modeling of Rock - Structure Interaction," prepared under ARPA Order No. 1579, Amend. 3 and monitored by the Spokane Mining Research Center, US Bureau of Mines under Contract H0220035. Dr. William J. Karwoski was the project monitor.

This computer program considers static, three-dimensional, nonlinear analyses by the finite element method. Gravity loading and sequence of excavation or construction are also considered. The following types of elements are available:

a. Beam

b. Rod

c. Axisymmetric quad

d. Plane quad

e. Three-dimensional hexahedron

f. Thick shell

g. Plane slip or joint

h. Axisymmetric slip or joint

All elements except the beam and thick shell may have nonlinear material properties. The types of nonlinear properties which may be assigned are:

a. Variable moduli

b. Elastic or variable modulus with ideal plasticity. Yield function may be isotropic or anisotropic

c. Nonlinear elastic with ideally plastic fracture criterion and strain hardening cap

d. Anisotropic variable moduli with anisotropic fracture criterion

e. Viscoelasticity (Kelvin, Maxwell, three-parameter fluid).

f. Viscoplasticity

The material properties are submitted as coefficients in an array whose length is 100 decimal locations. The coefficients are substituted into the appropriate equations according to flags. The user may easily change the form of any of the equations by modifying the material property subroutines, which can be done independently of the main line program. Small strains and small displacements are assumed. However, the program is written such that it can be modified to account for geometrical nonlinearity. The main provision in this regard is that the updated coordinates which are needed to form strain/displacement relationships and the original relationships are available in the computation section of the program.

The computer program was originally intended to solve problems in rock mechanics and mining engineering. Thus, the excavation and construction options are intended to aid analysis of shafts or chambers in rock having nonlinear properties from the start of construction through excavation and installation of temporary supports to the installation of permanent supports. Besides the problems shown in the final report cited above, the program has been applied to the pullout of a cable anchor embedded in soil. This problem uses axisymmetric elements with nonlinear properties and axisymmetric slip elements for slip and debonding.

The program uses the direct stiffness method of structural analysis. Degrees of freedom are defined at nodal points which are at corners of elements. Element stiffnesses are deposited in a global stiffness matrix. Nodal point forces, which include external loads and internal resisting forces are expressed in a global load vector. A form of Choleski decomposition, involving

triangularization of the global stiffness matrix, reduction of the load vector and back substitution of the reduced load vector into the triangularized stiffness matrix, is used to obtain incremental displacements. The program has several options for performing these operations from which it chooses depending on the available core. According to one option, the stiffness matrix is formed block by block (one bandwidth wide) and stored on peripheral units; it is then retrieved block by block and processed. Under a second option, the stiffness matrix and load vector are formed and reduced in a block-by-block manner and written on peripheral storage in a reduced form. Part of the reduction is performed in local double precision.

These operations require many accesses to peripheral storage. The number of accesses and hence the computer time required for large problems would become prohibitive on small or medium sized computers. In the present program, a multibuffering technique is used which allows data to be transferred to and from peripheral storage while computations are being performed in the main core area. This procedure virtually eliminates wait time for Input/Output operations.

The computer program is divided into three sections which are called Input, Execution, and Output. The responsibility of the user is greatest in the Input section, where the first step is to submit by means of coordinates on cards a key diagram which is the basis of the finite element mesh. The mesh, tributary areas and load coefficients are generated automatically, and the mesh is plotted. At this point the program will, on request, generate a restart tape and terminate execution so the user can examine the mesh he has prepared. Upon restarting, the user may add elements or nodal points, and he may request the bandwidth reducer to attempt reduction of the bandwidth. At this point a new plot of the mesh, which may have been expanded or renumbered or both, may be requested. The last group of data in the Input section includes element activity (an element may initially be inactive, become active, and then become inactive again) as a function of load step, load data (pressures in global directions) and material property data. At this point two tapes, a linkage file, and an element data file, linking Input to the Execution section are generated.

The Execution section is initialized using the two link tapes created by the input section. The user supplies the number of steps between reformulation of the global stiffness and the load step after which a restart file is to be generated.

To continue execution of a restarted problem, the previous restart tape replaces the linkage file, and the run is continued. Note that reformulation and restart intervals may be changed at this time.

The output is stored on a magnetic tape and is printed, on separate request by the user, by executing the Output section. Output may be requested after a restart has been generated, and after the run is completed.

SECTION 1

DEFINITION OF INPUT DATA

The input data cards for the computer program are described on the following pages.

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
1.0		OPTION SELECTION The following cards control the sequence of operations. Each option card is followed by the data required for execution, which is described in subsequent sections. Options may be stacked, but only in the sequence given below. 1. *STAR 2. *ADD data 3. *EXEC data 5 3 4. *OUTP 5. *EXIT This is a legal sequence allowing 1. Mesh generation 2. Modify generated mesh 3. Execute, reforming every fifth step and generate restart at Step 3 4. Print stresses, strains, and displacements 5. Termination A second run of the sequence: 1. *REST 5 (N) 2. *OUTP 3. *EXIT	

AA FORM NO. 1075

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
1.0 (cont)		Allows restart with reformulation every fifth step (optional restart at Step N) followed by output and termination.	
1.1	1	ISTR, IWITIN, NSTP, NRSTRT, TIMER ISTR = "*" control character identifies this card as an option selection IWITIN = Four-character abbreviation for the option desired MODI = MODIFY--alter contents of IWORDS array (see Card Group 2.0) STAR = START--call automesh to generate the mesh (see Card Group 3.0) ADD = Call automesh to add to an existing mesh (see Card Group 4.0) EXEC = EXECUTE--initiate calculation (no additional cards required) REST = RESTART--restart calculation (no additional cards required) OUTP = OUTPUT--begin output (no additional cards required) EXIT = End of run NSTP, NRSTRT, TIMER are used only by option EXEC and REST and should be blank for all others. NSTP = Step count for reformulation of the global stiffness, [K] will be reformed at every NSTPth cycle, must be > 0.	(A1,A4,5X, 2I10,F10.0)

AA FORM NO. 1075

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
1.1 (cont)		NRSTRT = Restart flag. A restart tape will be generated after step NRSTRT and calculation will be terminated. When restart is requested, the code prints a message indicating which file contains restart data. A run may be continued from this point by mounting this restart tape as the LINK tape (see Appendix C) and requesting option *REST. TIMER = Restart interval in seconds. A restart tape will be generated after TIMER seconds of execution, and the run will continue. Restart tape units are switched among available units. A restart unit is not released until a new restart tape has been written.	

AA FORM NO. 1075

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
2.0		INPUT FOR ALTERING IWORDS VIA OPTION "MODI". A DESCRIPTION OF IWORDS IS GIVEN IN APPENDIX A.	
2.1	variable	JTYPE, N JTYPE = Flag for type of alteration = I , value to be altered is integer (see 2.2) = H , value to be altered is Hollerith (see 2.3) = E , end of data for MODI N = Number of cards to be read Each JTYPE card must be followed by N cards containing data used to reset entries in the IWORDS array. These cards are defined in Groups 2.2 and 2.3.	(A1, I4)
2.2	N	INPUT CARDS FOR INTEGER DATA (JTYPE=I) JWD, IWD Set IWORDS (JWD) = IWD	(2I5)
2.3	N	INPUT CARDS FOR HOLLERITH DATA (JTYPE=H) JWD, IHOL IF (JWD ≠ 43), set IWORDS (JWD) = IHOL IF JWD = 43, read a new header card into IWORDS (43)-IWORDS (62). Card 2.3.1 must immediately follow the card with JWD = 43.	(I5, 1X, A4)
2.3.1	1	(IWD(I), I = 43,62)	(20A4)

AA FORM NO. 1075

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.0		AUTOMESH INPUT DATA--OPTION "START"	
3.1	1	(HED(I), I = 1, 20)	(20A4)
		HED = A 80-column label of alphameric characters used to identify the problem. This label will appear at the top of each printed output page	
3.2	1	NSPANY, NSPANX, NSPANZ, NMIDPT, NCOMFS, NCOMNP, ICOOR, NUMMAT, IPLOT, NSLIP, NPELAD, ITSHEL, IRENUM, JPLOT, IQUAD	(1515)
		NSPANY, NSPANX, NSPANZ = Number of "spans" or "blocks" in the x, y, and z directions, respectively, in the "key diagram." NSPANZ is not meaningful in a two-dimensional problem, and the corresponding field must be left blank.	
		NCOMFS = Number of faces (3-D case) or sides (2-D case) to be formed by the face- or side-joining process described in card group 3.11 (page 16).	
		NCOMNP $\geq$ Number of pairs of nodal points which will be joined by the face- or side-joining process in Card Group 3.11 (page 16).	
		ICOOR = A numeric flag specifying the units of length in which the input data is given. = 0 if the units are in feet = 1 if the units are in inches	

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.2 (cont)		If units selected are feet, the code converts all coordinates and areas into inches. Material property data is not converted and is expected to be given in inches. All final mesh data is expressed in inches. NUMMAT = Number of different materials in the finite element mesh. IPLOT = A numeric flag specifying if the generated mesh is to be plotted. = 0 if the mesh is not to be plotted = 1 if the mesh is to be plotted NSLIP = A numeric flag signifying the presence of slip elements = 0 if no slip elements are in the mesh = 1 if there are slip elements in the mesh When slip elements are present in a mesh, two runs must be performed. The actual number of slip elements is specified only in the second part of the run as explained in Card Group 4.1. NPELAD = A numeric flag specifying if there are nodal points and/or elements to be manually added in the second part of the run. = 0 if there are no nodal points and/or elements to be manually added	

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.2 (cont)		= 1 if there are nodal points and/or elements to be added. The actual number of nodal points and/or elements to be added are specified in Card Group 4.1. ITSHEL = A numeric flag signifying if there are shell elements involved in the mesh. = 0 if there are no shell elements = 1 if there are shell elements NOTE: If NSLIP, NPELAD, or ITSHEL are different from zero, a restart tape will be generated and option ADD must be run to complete the mesh. IRENUM = A numeric flag specifying if the final mesh, including all the manually added nodal points, elements, and slip elements is to be renumbered for possible smaller bandwidth. = 0 if the mesh is not to be renumbered. > 0 , IRENUM minutes will be allowed for the minimization JPLOT = A numeric flag that specifies if the renumbered mesh is to be plotted. This is the final mesh which will be used in the numerical calculation. = 0 if the final mesh is not to be plotted = 1 if the final mesh is to be plotted	

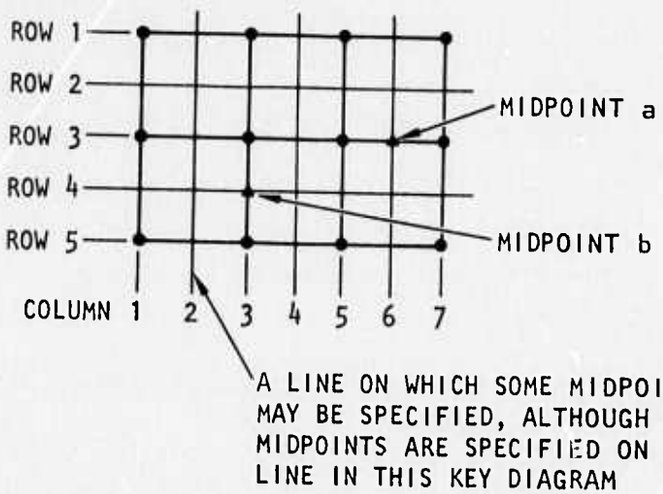
AJA FORM NO. 1075

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

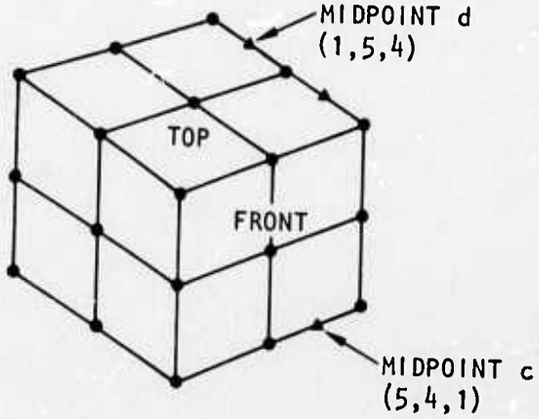
Card Group	No. of Cards	Data and Definitions	Fortran Format
3.2 (cont)		IQUAD = This variable is significant only in a two-dimensional run in which the mesh is automatically generated. It specifies if the quadrilaterals generated are plane strain, plane stress, or axisymmetric. = -3 or left blank. Quadrilaterals are plane strain. = 3 if the quadrilaterals are plane stress. = 4 if the quadrilaterals are axisymmetric.	
3.3	As req'd	X (I, J) (or R(I,J) if axisymmetric mesh) in a 2-D case and X (I, J, K) in a 3-D case X = X coordinates of the key diagram. Eight coordinates are given on a card, for as many cards as are necessary to define all the nodal points in the key diagram. They are given in the order: from the top to the bottom, from the left to the right, and in the 3-D case, from the front to the rear of the key diagram.	(8F10.0)
3.4	As req'd	Y (I, J) (or Z(I, J) if axisymmetric mesh) in a 2-D case and Y (I, J, K) in a 3-D case Y = Y coordinates of the key diagram. Given in the order as stated in X.	(8F10.0)

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.5	As req'd	Z (I, J, K) for a 3-D case only Z = Z coordinates in the key diagram. Given in the order as stated in X.	(8F10.0)
3.6	NMIDPT	I, J, X (I,J), Y(I,J) in a 2-D case and I, J, K, X(I, J, K), Y (I, J, K), Z (I, J, K) in a 3-D case I, J, K = positions, i.e., row, column and plane (or layer) numbers of a midpoint in the 2-D or 3-D array of nodal points and midpoints in the key diagram. As an example, in the 2-D key diagram shown below, Midpoints *a* and *b* occupy the positions (3,6) and (4,3), respectively.	(215,2F10.0) (315,3F10.0)



DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.6 (cont)		As another example, in the 3-D key diagram shown below Midpoints *c* and *d* have the positions (5, 4, 1) and (1, 5, 4), respectively.  X, Y, Z = CARTESIAN COORDINATES OF THE MIDPOINT	
3.7	As req'd	((MAT (I, J), I = 1, NSPANY), J = 1, NSPANX) in a 2-D case and	(1615)
		((MAT(I, J, K), I = 1, NSPANY), J = 1, NSPANX), K = 1, NSPANZ) in a 3-D case	(1615)
		MAT = Material number of a block in the key diagram, 16 numbers per card for as many cards as are necessary for all blocks. The material numbers of the blocks are given by following the arrangement of the blocks from the top to the bottom, from the left to the	

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

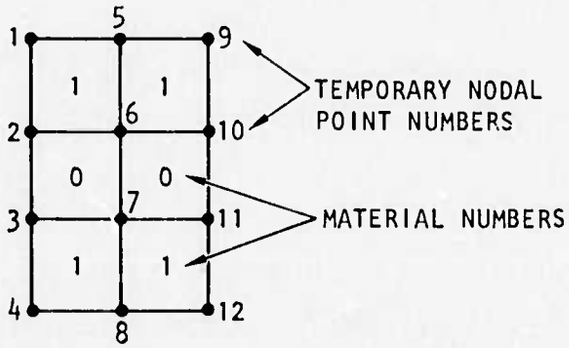
Card Group	No. of Cards	Data and Definitions	Fortran Format
3.7 (cont)		right, and then from the front to the rear in the key diagram. The material numbers must always start with 1, and a zero implies a void or a cutout.	
3.8	As req'd	(NDY (I), I = 1, NSPANY) NDY (I) = Number of divisions the blocks located in the Ith row of the key diagram are to be subdivided into in the y direction, 16 numbers per card.	(1615)
3.9	As req'd	(NDX (I), I = 1, NSPANX) NDX (I) = Number of divisions the blocks located in the Ith column of the key diagram are to be subdivided into in the x direction, 16 numbers per card.	(1615)
3.10	As req'd	(NDZ (I), I = 1, NSPANZ) for a 3-D case only NDZ (I) = Number of divisions the blocks in the Ith block layer are to be subdivided into in the z direction, 16 numbers per card.	(1615)
3.11	NCOMFS	N1, N2, M1, M2 for a 2-D case and N1, N2, N3, M1, M2, M3 for a 3-D case In a 2-D case: N1, N2 = The end points of a mesh line, or a segment of a mesh line, which is to be fused with another mesh line with end points M1 and M2 as defined next. N1, N2, M1, and M2 are temporary nodal point numbers that are used only in this card group to define nodal	(415)

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

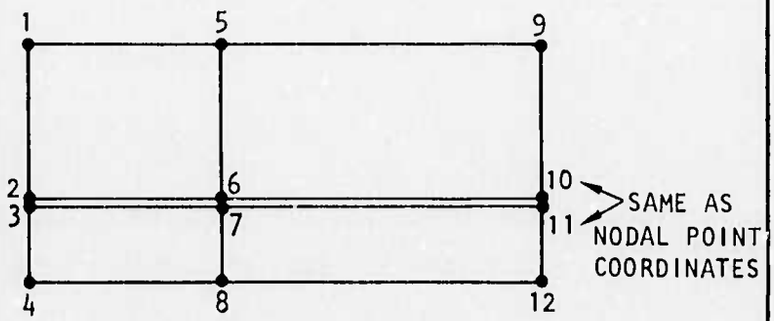
Card Group	No. of Cards	Data and Definitions	Fortran Format
3.11 (cont)		points to be joined in the key diagram. The nodal points are numbered from the top to the bottom and from the left to the right as illustrated in the example given below. M1, M2 = The end points of a second mesh line, or segment of a mesh line, which is to be fused with the first one. Naturally, there must be the same number of nodal points on this line as on the first line defined by N1 and N2. The two mesh lines are joined or fused in such a manner that M1 joins N1 and M2 joins N2. As an example, a rectangular mesh with a crack or a slip surface as shown in the figure below is the result of using the accompanying key diagram and specifying that mesh line 2-6 is to be fused with mesh line 3-7. Naturally, Nodal Points 2, 6, and 10 in the key diagram have to be given the same coordinates as Nodal Points 3, 7, and 11, respectively, in order to get the result indicated in the final mesh.	

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.11 (cont)		SCHEMATIC KEY DIAGRAM	



ACTUAL KEY DIAGRAM WITH THE CURRENT NODAL POINT COORDINATES



If it is specified that

1. mesh line 2-6 is to be joined to mesh line 3-7 and that
2. the number of divisions in the vertical and the horizontal direction are to be 2-1-1 and 2-2, respectively, then the following mesh is obtained.

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DEFINITION OF INPUT FOR
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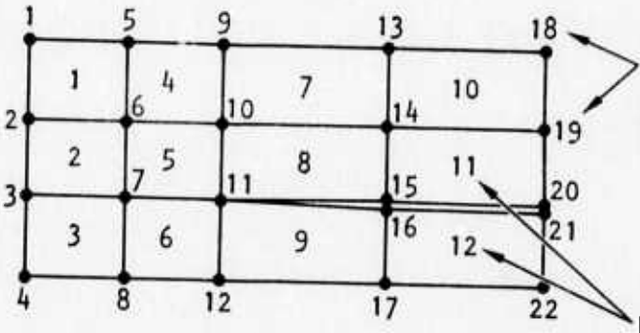
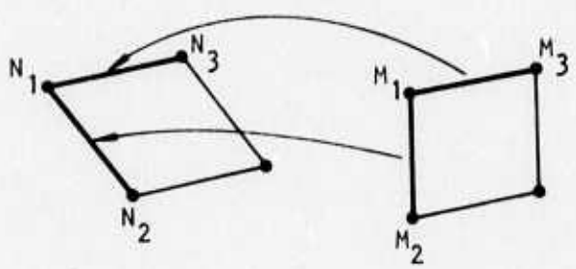
Card Group	No. of Cards	Data and Definitions	Fortran Format
3.11 (cont)		FINAL MESH  FINAL NODAL POINT NUMBERS AUTOMATICALLY ASSIGNED BY THE CODE FINAL ELEMENT NUMBERS Note that variable NCOMNP, the number of pairs of nodes to be joined, must be specified if face joining is to occur. In the above example, Line 2-6 includes three node points (Nodes 3, 7, and 11 in the final mesh) so that NCOMNP = 3.	

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.11 (cont)		In the 3-D example below, NCOMNP would equal the total number of nodes generated on face N1-N2-N3 (which must, of course, equal those on M1-M2-M3). In a 3-D case: N1, N2, N3 = Three corners of a four-sided face which is to be fused with another face as defined by the corner points M1, M2, and M3, as explained below. N1, N2 ... M3 are temporary nodal point numbers that are used only in this card group to define nodal points to be joined in the key diagram. The nodal points are numbered from the top to the bottom, from the left to the right, and from the front to the rear of the key diagram. The three points, N1, N2, and N3 must be so specified that N1 represents the corner formed by the two sides N1-N2 and N1-N3, as shown in the following illustration.  M1, M2, M3 = Three corners of a second four-sided face which is to be fused with the first face as described above. The fusion takes place	

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DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.11 (cont)		in such a manner that M1, M2, and M3 coincide with N1, N2, and N3, respectively, as illustrated in the above figure.	
3.12	1	(ISIDE(I), I = 1, 4), NN for a 2-D case and (ISIDE(I), I = 1, 6), NN for a 3-D case In a 2-D case: ISIDE(I) = A number, 1 through 4, representing any one of the four sides of a key diagram for which boundary codes are to be automatically generated by the program. The top side is designated 1, the bottom 2, the left 3, and the right 4, and these numbers may be given in any order. Thus, 2400 has the same effect as 0402; both of them say that boundary codes are to be automatically generated for the bottom and the right side of the key diagram only. It must be emphasized that boundary codes can be automatically generated only for those cases in which the sides designated conform to the following requirements. For a side of the mesh which corresponds to either the top or the bottom side of the key diagram, the side must be parallel to the x-axis, and for a side of the mesh which corresponds to either the left or the right side of the key diagram, the side must be parallel to the y-axis. A blank card, however, has to be supplied, even when no such automatic generation is desired.	(4I1, 6X, I5) (6I1, 4X, I5)

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DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.12 (cont)		In a 3-D case: ISIDE(I) = A number, 1 through 6, representing any one of the six side faces of a key diagram for which boundary codes are to be automatically generated by the program. The front face is designated 1, the rear, 2, the top 3, the bottom 4, the left 5, and the right 6. All the rest of the comments given above for the 2-D case also apply to this case. As before, a blank card must be supplied even when no such generation is desired. Both in a 2-D and a 3-D case: NN = Total number of nodal points for which boundary codes are to be read in manually. Refer to the explanation given in the next card group.	
3.12.1	NN	J, (KODE (I, J), I = 1, 6) J = Final nodal point number of a nodal point whose boundary codes are to be manually read in. KODE = Boundary condition codes for the six degrees of freedom associated with the nodal point. = 0 when the degree of freedom is not constrained. = 1 when the degree of freedom is constrained. Thus, a card which reads 25 011101 says that at Nodal Point 25 only the x-displacement and the y-rotation are left unconstrained.	(I5, 1X, 6I1)

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DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.13	1	(ISIDE (I), I = 1, 4), NN for a 2-D case and (ISIDE (I), I = 1, 6), NN for a 3-D case Numbers specified in this card group parallel those given in Card Group 3.12. The only difference is that the numeric flags given in ISIDE array here designate the sides or faces for which the nodal tributary areas and load coefficients are to be calculated automatically, and NN specifies the total number of nodal points for which tributary areas and load coefficients are to be read in manually from the next card group. All other comments given in Card Group 3.12 apply. As before, a blank card must be supplied even when no such automatic generation is desired. (The code cannot generate tributary areas for axisymmetric elements.)	(411, 6X, I5) (611, 4X, I5)
3.14	NN	J, (TA (I, J), I = 1, 3) J = Final nodal point number. TA = Three tributary areas associated with the three components of the nodal force acting at Nodal Point J. They should be in square ft, if the coordinates of the nodal points in the key diagram have been specified in feet. In the code, the x-component of the nodal force acting at Nodal Point J, for example, is defined as $P_x \cdot TA\ (I, J) \cdot C(I, J)$	(I5,3F10.0)

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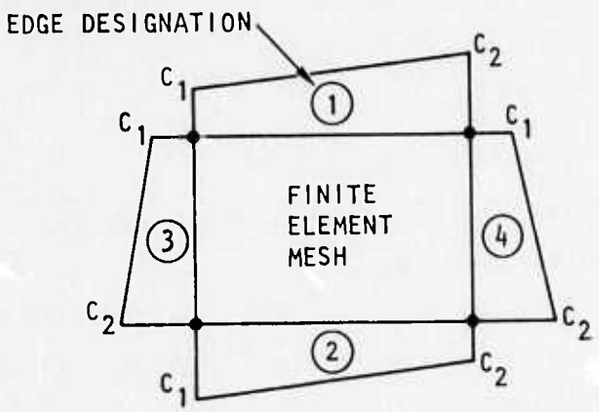
DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.14 (cont)		where P_x is the horizontal pressure for the system to be specified later.	
3.15	0 ~ 4	C1, C2 for a 2-D case and	(2F10.0)
	0 ~ 6	(CC (I), I = 1, 4) for a 3-D case	(4F10.0)
		In a 2-D case:	
		C1, C2 = The values of the load coefficient at the two ends of the corresponding edge specified in the last card group. One such card must be supplied for each one of the edges specified in the ISIDE array, and these cards must be arranged in the same order as the edges are mentioned in the ISIDE array. The following figure defines the corners the two C-values are referred to for each one of the four edges:	
			
		When the value of C is to be a constant along an edge the user may give a negative sign to C1 and leave the field for C2 blank.	

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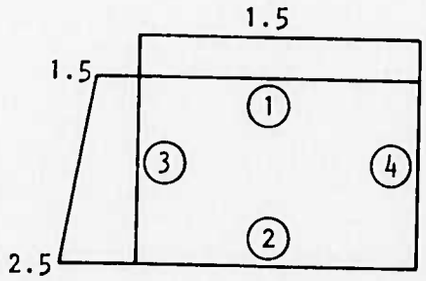
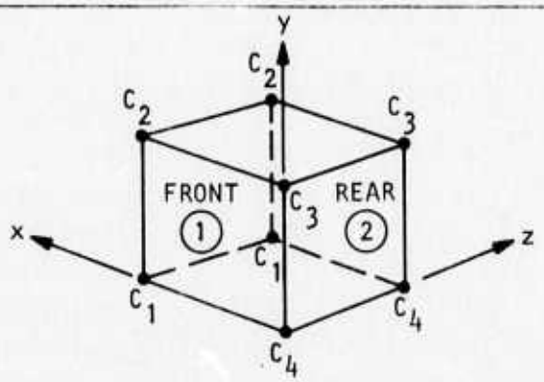
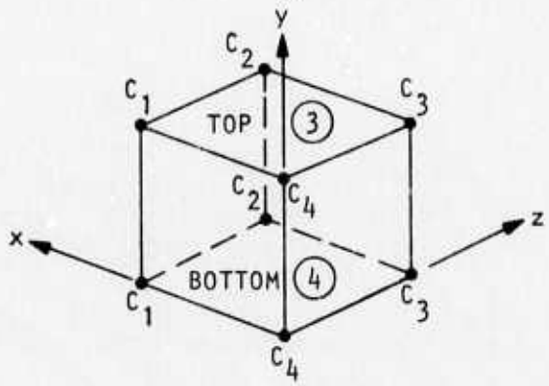
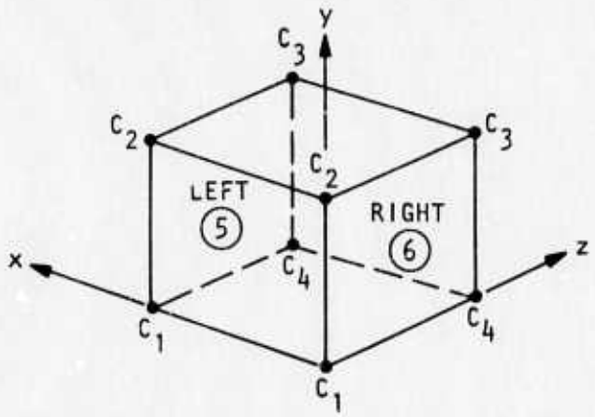
DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.15 (cont)		As an example, if ISIDE in Card Group 3.13 read 3100, or 0301, or 0031 (as long as 3 precedes 1, that is), one would be specifying the following variation in the C coefficient by providing the following two cards in this card group. First card: 1.5 2.5 Second card: -1.5  In case a blank card is supplied in Card Group 3.13 (implying 0000), no card in this card group is expected by the program. In a 3-D case: CC (1) - CC (4) = The values of the load coefficient at the four corners of the corresponding side face specified in Card Group 3.13. All the comments given above for the 2-D case apply. The following figures define the points of definition of the four coefficients for each side face.	

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.15 (cont)		   As before, a constant value of the coefficient over a side face can be specified simply by giving CC(1) a negative sign and leaving the remaining three fields blank. In case the ISIDE card in Card Group 3.13 is blank, the program expects to read no card in this card group.	

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DEFINITION OF INPUT FOR

BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.16	NN	J, (C(I, J), I = 1, 3) J = Final nodal point number C = Three load coefficients associated with the three components of the nodal force acting at Nodal Point J.	(I5,3F10.0)
3.17	1	(VIEW (I), I = 1, 6) for a 3-D case only VIEW (1 ~ 3) = Direction cosines of the horizon which extends from the left toward the right. VIEW (4 ~ 6) = Direction cosines of the view vector (line of sight). The plot controls specified in this card group are for the plot of the mesh automatically generated by the program. No cards are expected in this and the following two card groups in case IPLOT = 0.	(6F10.0)
3.17.1	1	QSIZE, HTNODE, HTELE, NCUT QSIZE = Width in inches of the paper to be used if different from the default value of 10.6 in. HTNODE = Height in inches of the nodal point numbers if different from the default value of 0.07 in. HTELE = Height in inches of the element numbers if different from the default value of 0.08 in. If IPLOT = 0 this card is not supplied.	(3F10.0, I10)

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DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
3.17.1 (cont)	1	NCUT = Number of sections to be defined in the next card group which will define the portion of the mesh to be plotted. As has been noted, this card group is provided only when IPLOT = 1.	
3.17.2	NCUT	((XCUT (I, J), I = 1, 6), J = 1, NCUT) XCUT (1 ~ 3, J) = Cartesian coordinates of a point on the Jth cut plane. XCUT (4 ~ 6, J) = Direction cosines of a normal to the cut plane. The normal must be specified in such a manner that it points toward the side of the cut plane which is to be plotted. This card group is provided only when IPLOT = 1. For a run which does not contain any nodal points, elements or slip elements to be manually added, the next card group to be supplied is Card Group 4.5.	(6F10.0)
4.0		AUTOMESH RESTART DATA (OPTION "ADD")	
4.1	1	NSLIP, NNPADD, NELADD, NOBB, NUMMAT NSLIP = Number of generated elements to be assigned as slip elements in Card Group 4.2. NNPADD = Total number of nodal points to be added. NELADD = Total number of elements to be added. NOBB = Number of bar and beam elements to be added (also included in NELADD).	(5I5)

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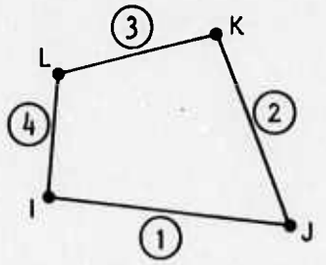
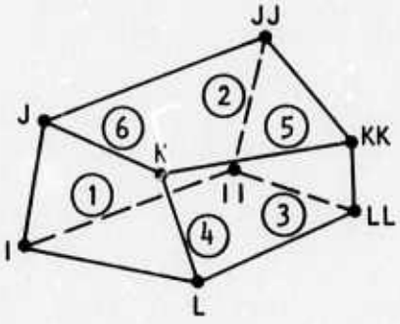
DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.1 (cont)		NUMMAT = Number of material property sets to be supplied	
4.2	NSLIP	(NESLIP(N), SLIPDA(1,N), (IIJJ(J,N), J = 1,2), (SLIPDA(J,N), J = 2,3), N = 1, NSLIP) for a 2-D case and	(515, F10.0)
		(NESLIP(N), SLIPDA(1,N), (IIJJ(J,N), J = 1,4), (SLIPDA(J,N), J = 2,3), N = 1, NSLIP)	(715, F10.0)*
		NESLIP(N) = Element number of an existing element (automatically generated in the first run) which is to be associated with a slip element.	
		SLIPDA(1,N) = A numeric flag designating the side (2-D) or face (3-D) which constitutes part of the slip surface. The following figures define the numeric designation. Which corner nodal point is called I,J,K, etc., can be determined by referring to the printout of the first run.	





*Not implemented.

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.2 (cont)		IIJJ = The nodal poin numbers of the nodal points which are located on the other side of the slip surface, directly opposite to the nodal points constituting the corners of the side or side face designated by ISLIP. In the case of a 2-D problem, there are two such points for each slip element, and in the case of a 3-D problem, there are four such points for each element. These additional nodal points must be specified in the following order of the pairing nodal points: 2-D case: ISLIP = 1 I, J ISLIP = 2 J, K ISLIP = 3 K, L ISLIP = 4 L, I 3-D case: ISLIP = 1 I, J, K, L ISLIP = 2 J, K, KK, JJ ISLIP = 3 K, L, LL, KK ISLIP = 4 L, I, II, LL ISLIP = 5 II, JJ, KK, LL ISLIP = 6 I, J, JJ, II SLIPDA (2,N) and SLIPDA (3,N) = The material number and the thickness, respectively, of the associated slip element located on the slip surface.	

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DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.3	NELADD	ITYPE, (IX (I), I = 1, 8), MAT ITYPE = Numeric designation of the element type. -3 = Quadrilateral under plane strain condition -1 = Bar under plane strain condition 1 = Bar under plane stress condition 2 = Beam element 3 = Quadrilateral under plane stress condition 4 = Axisymmetrical element 5 = Brick element 6 = Thick shell element 7 = Quadrilateral-slip element 8 = Brick-slip element 9 = Axisymmetric slip element IX = Element connectivity array. The nodal points must be given in the following sequence: Bars: Either end first Beams: The two ends and then the reference point	(1015)

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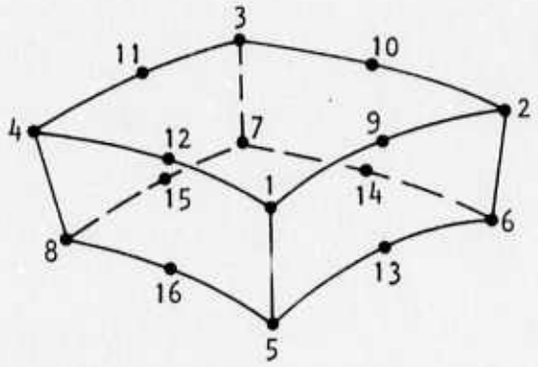
DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.3 (cont)		Quadrilaterals: I, J, K, L in the counter-clockwise sense as shown in the figure on Page 36. Bricks: I, J, K, L, II, JJ, KK, LL, as shown in the second figure on Page 36. Notice that when the brick is viewed in such a manner that the front face, I-J-K-L, is closer to the viewer, I-J-K-L, follow the clockwise sense, and that II on the rear face is located on the same edge as I, etc. Thick shells: The 16 nodal points involved are specifled in the sequence pictured in the following figure:  Quad-slip and axisym-slip elements: I,J, K, L for the quadrilateral in the sequence already explained, and then the two additional nodal points as explained under Card Group 4.2, Item IIJJ.	

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DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.3 (cont)		Brick-slip elements:* Eight nodes of the brick, I, J, K, L, II, JJ, KK, LL followed by the four additional nodes as explained under Card Group 4.2, Item IIJJ. Notice that when the number of nodal points involved is less than eight, some fields on the card are skipped before MAT is specified. However, when the number of nodal points exceeds eight, as in a thick-shell element, the extra nodal points are punched on an additional card in the format (8I5). The reading of this extra card is controlled by the value of ITYPE. MAT = Material number of the element	
4.4	NNPADD	(KODE (I), I = 1, 6), X, Y, Z, (TA (I), I = 1, 3), (COEF (I), I = 1, 3) These are data for the addition of nodal points. KODE = Six single-digit numeric flags specifying the constrained condition on the six degrees of freedom at the nodal point. 0 means unconstrained and 1 means constrained. The six degrees of freedom are arranged in the following order: 1 x-displacement 2 y-displacement 3 z-displacement 4 x-rotation (rotation about the x-axis)	(6I1, 2X, 9F8.0)

*Not implemented

DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.4 (cont)		5 y-rotation 6 z-rotation x, y, z = Cartesian coordinates of the nodal point. TA = Tributary areas associated with the three components of the external pressure acting at the point. COEF = Values of the C coefficient associated with the three external pressure components. The x component of the nodal force acting at a point, for example, is eventually computed as $F_x = P_x \cdot TA_x \cdot COEF_x$ where P_x is the x component of the external pressure.	
4.5	1	NACTIV NACTIV = Number of elements with activity supplied.	(I5)
4.5.1	NACTIV	NEL, ION, IOFF NEL = Element number ION = Step number at which element becomes active IOFF = Step number at which element becomes inactive	(3I5)
4.6	1	IDLFLG, NDLINC, (DCOSGR (I), I = 1, 3) IDLFLG = 1, output is relative to dead loading = 2, displacements include dead loads NDLINC = Number of increments in which to apply dead loads = 0 do not apply dead load	(2I5,3F10.0)

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DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.6 (cont)		DCOSGR = Coefficients of gravity load in X, Y, and Z directions Dead-load components in the X, Y, and Z direction are computed via $DCOSGR_X$ * ρ * volume $DCOSGR_Y$ * ρ * volume $DCOSGR_Z$ * ρ * volume	
4.7	1	NLSTEP NLSTEP = Maximum number of live-load steps	(I5)
4.7.1	NLSTEP	TIME, PX, PY, PZ Time = Time associated with load step PX, PY, PZ = Pressure loads in X, Y, and Z directions The following three groups of cards are similar to Card Group 3.17. They provide controls for the plotting of the final mesh, after any nodal point and/or element renumbering has been performed.	(4F10.0)
4.8	1	(VIEW (I), I = 1, 6) for a 3-D case only	(6F10.0)
4.8.1	1	QSIZE, HTNODE, HTELE, NCUT	(3F10.0, I10)
4.8.2	NCUT	((XCUT (I,J), I = 1,6), J = 1, NCUT)	(6F10.0)
4.9		Material Properties--NUMMAT sets (see Appendix B)	
4.9.1	1	B, G, RHO B = Bulk modulus G = Shear modulus RHO = Density	3F10.0

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DEFINITION OF INPUT FOR
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Card Group	No. of Cards	Data and Definitions	Fortran Format
4.9.2	1	NISO, NPL, NVISC, ITER, NSPLIT, NITER NISO = Isotropic flag NPL = Plasticity flag NVISC = Viscoelastic flag ITER = Iteration flag NSPLIT = Number of splits NITER = Number of iterations	(6I10)
4.9.3	1	DELTA, CONV, NVM DELTA = Split criterion CONV = Convergence criterion NVM = Variable modulus flag	(2F10.0,I10)
4.9.4	3	(GCOEF (I), I = 1, 20) Shear modulus coefficients	(3(8F10.0))
4.9.5	9	(BCOEF (I), I = 1, 40), (YCOEF (I), I = 1, 25) BCOEF = Bulk modulus coefficients YCOEF = Inelasticity coefficients	(7(8F10.0), 3F10.0,2I10, 3F10.0/F10.0)
4.10	NOBB	Additional data for bars and beams ((ADBB (I, J), I = 1, 8), J = 1, NOBB) ADBB (1 ~ 8, J) = The additional element data required for the Jth bar or beam element. Cards in this card group must be so arranged that each card comes up in the same sequence as the corresponding element card is encountered in Card Group 4.3.	(6F10.0, 2I10)

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DEFINITION OF INPUT FOR
BUREAU OF MINES CODE

Card Group	No. of Cards	Data and Definitions	Fortran Format
4.10 (cont)		In the case of a bar element, ADBB (1, J) = cross-sectional area of the bar. ADBB (2, J) = Initial stress in the bar. In the case of a beam element, ADBB (1, J) = A_x, the cross-sectional area of the beam. ADBB (2, J) = A_y, the shear area with respect to the local y-axis. ADBB (3, J) = A_z, the shear area with respect to the local z-axis. ADBB (4, J) = I_2, the second moment of the cross-sectional area with respect to the local y-axis. ADBB (5, J) = I_3, the moment of the cross-sectional areas with respect to the local z-axis. ADBB (6, J) = I_{xy} or J, the polar moment of inertia of the cross-section. If this field is left blank J will be computed as $J = I_2 + I_3$. ADBB (7, J) and ADBB (8, J) = The two end-release codes for the beam.	

APPENDIX A

CONTENTS OF IWD COMMON BLOCK

Common block IWD contains constants and variables used throughout the program. The user may reset the default values listed below by involving option "MODI" (see Card Group 2.0 in the data definition).

Location	Name	108 Default Value	Meaning
1	IWCD	5	Card reader unit number
2	IWPRT	6	Printer unit number
3	IWPUNC	-3	Punch unit number
4	IWCOMP	1108	Computer code
5	IWSRUN	0	Debug flag
6	IWCORE	27000	Length of BMCALC common
7	IWDEOF	4HDEOF	End of file word
8	IWBLNK		Hollerith code for blank
9	IWITIN	(not set)	Current itinerary option
10	IWRUN(1)	4HMODI	Allowable itinerary options
11	IWRUN(2)	4HSTAR	
12	IWRUN(3)	3HADD	
13	IWRUN(4)	4HEXEC	
14	IWRUN(5)	4HREST	
15	IWRUN(6)	4HOUTP	
16	IWRUN(7)	4HEXIT	
17-19		(Not used)	
20	IWNRUN	10	Length of IWRUN
21	IWTAPE	8	Number of tape units
22	IWDRUM	9	Number of drum units
23	IWLUN(1)	9	Tape or drum logical unit numbers
24	IWLUN(2)	11	
25	IWLUN(3)	13	
26	IWLUN(4)	7	
27	IWLUN(5)	12	
28	IWLUN(6)	14	
29	IWLUN(7)	8	
30	IWLUN(8)	10	

Location	Name	1108 Default Value	Meaning
31	IWLUN(9)	21	(Tape or drum logical unit number)
32	IWLUN(10)	22	
33	IWLUN(11)	38	
34	IWLUN(12)	39	
35	IWLUN(13)	40	
36	IWLUN(14)	41	
37	IWLUN(15)	42	
38	IWLUN(16)	43	
39	IWLUN(17)	44	
40	IWLUN(18)	0	
41	IWLUN(19)	0	
42	IWLUN(20)	0	
43-62	IWHDR(1)-IWHDR(20)	Blanks	Contain run title
63	IWNNP	Not set	Number of node points
64	IWNEL	Not set	Number of elements
65	IWNMAT	Not set	Number of materials
66	IWBAND	Not set	Bandwidth
67	IWNEQ	Not set	Number of equations (DOF's)
68	IWNLDB	Not set	Number of entries/load coefficient block
69	IWNREC	Not set	Number of load coefficient blocks
70	IWNCF	3	Number of columns in load vector
71	IWNEQB	Not set	Number of equations/block
72	IWNEU	Not set	Size of element data block
73	IWERR	0	Error flag
74	IWLPPG	50	Maximum lines/page
75	IWKEN	27000	Length of ATOMSH common
76-100	IWDUM	Not used	
101	LMSTRT	21	Pointer to start of LM array
102	NRSTRT	Not set	Restart step number

Location	Name	1108 Default Value	Meaning
103	TIMER	Not set	Restart time interval
104	NSTP	99999	Reformulation interval
105	MAXSTP	Not set	Maximum number of load steps
106	NLDI	Not set	Number of dead load increments
107	NCOL	4	Number of columns in load vector

APPENDIX B

DEFINITION OF MATERIAL PROPERTY COEFFICIENTS

The coefficients which define the stress/strain properties for each material (N) are stored in an array COEFF(I,N), I = 1,100. The COEFF array is divided into three main sections as follows:

1.	COEFF(I,N), I = 1,15	Set linear elastic, isotropic moduli select options for material models, select coefficients controlling integration of stress/strain relations
2.	COEFF(I,N), I = 16-35	Coefficients defining variable shear moduli
	COEFF(I,N), I = 36-75	Coefficients defining variable bulk moduli
3.	COEFF(I,N), I = 76-100	Coefficients defining inelastic models (plasticity, viscoplasticity, viscoelasticity)

Although the properties are initially read into the COEFF array, they are subsequently transferred into dimensionless variables and one dimensional working arrays whose names suggest their meaning as shown in the input definition. Thus:

Shear Modulus(G)	COEFF(I,N), I = 16,35)	=	GCOF(I), I = 1,20
Bulk Modulus(B)	COEFF(I,N), I = 36,75)	=	BCOF(I), I = 1,40
Inelasticity Coefficients(Y)	COEFF(I,N), I = 76,100)	=	YCOF(I), I = 1,25

To make writing formulas easier in the following discussion, the notation G, B, and Y is used to indicate the various coefficients. Thus

G_1 to G_{20} = Shear modulus coefficients

B_1 to B_{40} = Bulk modulus coefficients

Y_1 to Y_{29} = Inelasticity coefficients

The dimensions of the material properties are expressed in the inch-pound-second system.

ELASTIC MODULI AND CONTROL COEFFICIENTS (COEFF(I,N), I = 1,15)

COEFF(1,N) (B) = Elastic bulk modulus; constant value to be used for isotropic material. May be used with plastic viscoplastic or viscoelastic material.

COEFF(2,N) (G) = Elastic shear modulus; constant value to be used for isotropic material. May be used with plastic, viscoplastic or viscoelastic material.

COEFF(3,N) (RHO) = Mass density

COEFF(4,N) (NISO) = Anisotropy flag

= 0 Isotropic

= 1 Elastic, ideally plastic with anisotropic yield function suggested by Hill

= 2 Anisotropic moduli with anisotropic fracture criterion

COEFF(5,N) (NPL) = Inelasticity flag

= 0 Elastic

= 1 Ideally plastic

= 2 Strain hardening (cap model)

COEFF(6,N) (NVISC) = Viscous property flag

= 0 Inviscid

= 1 Viscoplastic

= 2 Viscoelastic

COEFF(7,N) (ITER) = Iteration flag. The integration of nonlinear stress/strain relations may require iteration if tangent moduli are implicit functions of stress and strain components. This is especially true of the cap model and sometimes true of variable moduli models.

= 0 For iteration

≠ 0 No iteration

COEFF(8,N) (NSPLIT) = Strain subdivision flag for viscoplastic materials. To compute stress relaxation correctly, the strain increment is subdivided into NSPLIT smaller increments. This number, which may need to be as high as 50, applies to viscoplastic materials only.

COEFF(9,N) (NUMITR) = Number of iterations. This flag is used with ITER = 0. Iteration proceeds until convergence is reached within a prescribed tolerance (see CONV below) or until the number of iterations equals NUMITR. May be about 8 to 10.

COEFF(10,N) (SPLIT) = Strain subdivision flag for materials other than viscoplastic. Subdivision may occur when a trial stress increment exceeds a predetermined value or when the trial stress state should be exactly on a yield surface but if off by greater than a predetermined value.

DELTA > 0. for strain subdivision whenever $|d\sigma_{ij}|_{trial} >$ DELTA. In this case, d_{ij} are divided into DELTA subincrements.

DELTA < 0. for strain subdivision whenever

$$F = \left| \frac{f(\sigma_{ij})_{trial}}{\left(\sqrt{J_2'}\right)_{trial}} - 1. \right| > CONV$$

where

$f(\sigma_{ij})_{trial}$ is the value of $\sqrt{J_2'}$ on the current yield surface, and $\sqrt{J_2'}$ is the trial value of the second invariant of the stress deviator.

In this case, the number of strain subincrements is

$$\left|(d\sigma_{ij})_{max}\right|_{trial} * CONV/F$$

where

$\left|(d\sigma_{ij})_{max}\right|_{trial}$ is the largest of the trial stress increments.

To avoid subdividing strain increments, set DELTA >> $\left|(d\sigma_{ij})_{max}\right|_{trial}$

COEFF(11,N) (CONV) = Criterion for convergence of iteration (see ITER). Also used to control strain subdivisions (see NSPLIT). Convergence is defined if

$$|a-b| < CONV*a$$

where

$$a = \left| |d\sigma_{11}| + |d\sigma_{22}| + |d\sigma_{33}| \right|_{previous\ step}$$

$$b = \left| |d\sigma_{11}| + |d\sigma_{22}| + |d\sigma_{33}| \right|_{current\ step}$$

COEFF(12,N) = Variable modulus flag
(NVM)

= 0 For constant moduli (uses B and G above)

= 1 For variable moduli

COEFF(13,N), COEFF(14,N), COEFF(15,N) are presently unused.

SHEAR MODULI COEFF(16,N) through COEFF(35,N) (GC)F(1) through GC)F(20))

Case 1 (Isotropic, constant moduli)
(N1SO = 0, NVM = 0) GCOF(1) through GCOF(20) = 0

Case 2 (Isotropic, variable moduli)
(N1SO = 0, NVM = 1) Shear moduli are defined to be a function of the elastic component of volumetric strain μ.

Loading ($\mu < \mu_{max} \leq 0$) where μ_{max} is the smallest previous value of μ.

$$G = G_2 - (G_2 - G_1) \exp(-\mu/G_3)$$

Unloading/Reloading ($\mu_{max} < \mu \leq 0$)

$$G = G_2 - (G_2 - G_1) \exp(-\mu_{max}/G_3)$$

Tension ($\mu > 0$)

$$G = G_{10}$$

For Case 2

COEFF(N,16) = G_1

COEFF(N,17) = G_2

COEFF(N,18) = G_3

COEFF(N,25) = G_{10}

Case 3 (N1SO = 1, NVM = 0) (Constant, anisotropic moduli, may be used with anisotropic yield criterion of Hill).

$$COEFF(N,16) = G_{12}$$

$$COEFF(N,17) = G_{13}$$

$$COEFF(N,18) = G_{23}$$

Case 4 (N1SO = 2, NVM = 1) (Variable anisotropic moduli to be used with anisotropic fracture criterion of Jaeger. May be used for plane geometry only. Data on fracture criteria must be specified through JCOF. Fracture occurs when

$$f = (\sigma_1 - \sigma_3) - \left(\frac{2a_o - 2a_1\sigma_3}{a_1 - \sqrt{a_1^2 + 1}}\right) < 0$$

elastic $(f \geq 0)$

$$COEFF(N,16) = G_{12} \text{ (elastic)}$$

$$COEFF(N,17) = G_{13} \text{ (elastic)}$$

$$COEFF(N,18) = G_{23} \text{ (elastic)}$$

inelastic $(f \leq 0)$

$$COEFF(N,19) = G_{12} \text{ (inelastic)}$$

$$COEFF(N,20) = G_{13} \text{ (inelastic)}$$

$$COEFF(N,21) = G_{23} \text{ (inelastic)}$$

BULK MODULI/YOUNG'S MODULI AND POISSON RATIO
COEFF(36,N) through COEFF(75,N) (BCOF(1) through BCOF(40))

Case 1 (Isotropic, constant moduli)
(NISO = 0, NVM = 0) BCOF(1) through BCOF(40) = 0.

Case 2 (Isotropic, variable moduli)
(NISO = 0, NVM = 1) Bulk moduli are defined to be a function of the elastic component of volumetric strain μ.

Loading ($\mu < \mu_{max} \leq 0$) where μ_{max} is the smallest previous value of μ

$$B = B_1 - (B_1 - B_2) \exp(\mu/B_4)$$

Unloading/Reloading ($\mu_{max} < \mu \leq 0$)

$$B = \bar{B} + (B_1 - \bar{B})\mu/B_5$$

where

$$\bar{B} = \text{Lesser of} \begin{cases} B_2 - (B_1 - B_2)\mu_{max}/B_5 \\ B_1 \end{cases}$$

Tension $\mu > 0$

$$B = B_{10}$$

For Case 2

COEFF(N,36) = B_1
COEFF(N,37) = B_2
COEFF(N,38) = B_3 (presently not used)
COEFF(N,39) = B_4
COEFF(N,40) = B_5
COEFF(N,45) = B_{10}

Case 3 (N1SO = 1, NVM = 0) (Constant anisotropic moduli. May be used with anisotropic yield criterion of Hill)

$$COEFF(N,36) = B_1 = E_1$$
$$COEFF(N,37) = B_2 = \nu_{12}$$
$$COEFF(N,38) = B_3 = \nu_{13}$$
$$COEFF(N,39) = B_4 = B_2$$
$$COEFF(N,40) = B_5 = \nu_{21}$$
$$COEFF(N,41) = B_6 = \nu_{23}$$
$$COEFF(N,42) = B_7 = E_3$$
$$COEFF(N,43) = B_8 = \nu_{31}$$
$$COEFF(N,44) = B_9 = \nu_{32}$$

Case 4 (N1SO = 2, NVM = 1) (Variable anisotropic moduli to be used with anisotropic fracture criterion of Jaeger, may be used for plane geometry only. Data on fracture criteria must be specified through YCOF. Fracture occurs when

$$f = (\sigma_1 - \sigma_3) - \left(\frac{2a_0 - 2\,a_1\sigma_3}{a_1 - \sqrt{a_1^2 + 1}}\right) < 0$$

elastic ($f \geq 0$)

$$COEFF(N,36) = B_1 = E_1$$
$$COEFF(N,37) = B_2 = \nu_{12}$$
$$COEFF(N,38) = B_3 = \nu_{13}$$
$$COEFF(N,39) = B_4 = E_2$$
$$COEFF(N,40) = B_5 = \nu_{21}$$
$$COEFF(N,41) = B_6 = \nu_{23}$$

COEFF(N,42) = B_7 = E_3

COEFF(N,43) = B_8 = ν_{31}

COEFF(N,44) = B_9 = ν_{32}

inelastic (f < 0)

COEFF(N,46) = B_{11} = E_1

COEFF(N,47) = B_{12} = ν_{12}

COEFF(N,48) = B_{13} = ν_{13}

COEFF(N,49) = B_{14} = E_2

COEFF(N,50) = B_{15} = ν_{21}

COEFF(N,51) = B_{16} = ν_{23}

COEFF(N,52) = B_{17} = E_3

COEFF(N,53) = B_{18} = ν_{31}

COEFF(N,54) = B_{19} = ν_{32}

COEFF(N,55) through COEFF(N,65) not used.

COEFF(N,66) through COEFF(N,74) contain direction cosines for anisotropic materials as follows:

GLOBAL AXIS

PRINCIPAL AXIS OF ANISOTROPY	X	Y	Z
X'	B_{31}	B_{34}	B_{37}
Y'	B_{32}	B_{35}	B_{38}
Z'	B_{33}	B_{36}	B_{39}

COEFF(N,66) = B_{31}

COEFF(N,67) = B_{32}

COEFF(N,68) = B_{33}

COEFF(N,69) = B_{34}

COEFF(N,70) = B_{35}

COEFF(N,71) = B_{36}

COEFF(N,72) = B_{37}

COEFF(N,73) = B_{38}

COEFF(N,74) = B_{39}

COEFF(N,75) = B_{40} = PSI (CCW angle from major principal stress axis to bedding planes at which cohesion of anisotropic rock is a minimum)

COEFFICIENTS DEFINING INELASTICITY
COEFF(N,76) through COEFF(N,100) (YCOF(1) through YCOF(25))

Case 1
(NPL = 1)

Elastic, ideally plastic yield criterion. Two functions are available, depending on value of ITYPE = COEFF(N,95).

For ITYPE ≠ 2, material may be isotropic or anisotropic (Hill's criterion) depending on values of coefficients. Principal directions of anisotropy are submitted through direction cosines in BCOF. For ITYPE = 2, criterion is that used with cap model, but cap is not available unless NPL = 2.

(NPL = 1, ITYPE ≠ 2)

Polynominal yield surface, with von Mises limit at high pressure, in terms of J_1^*, $\sqrt{J_2}^*$

$$J_1^* = Y_1\sigma_{11} + Y_2\sigma_{22} + Y_3\sigma_{33}$$

$$\sqrt{J_2'}^* = \left\{ \frac{1}{6} \left[Y_4 (\sigma_{11} - \sigma_{22})^2 + Y_5 (\sigma_{22} - \sigma_{33})^2 + Y_6 (\sigma_{33} - \sigma_{11})^2 + Y_7\sigma_{13}^2 + Y_8\sigma_{23}^2 + Y_9\sigma_{12}^2 \right] \right\}^{1/2}$$

for $J_1^* > Y_{10}$

$$f_1 (J_1^*, \sqrt{J_2'}) = Y_{11} + Y_{12}J_1^* + Y_{13} (J_1^*)^2 + Y_{14} (J_1^*)^3 - \sqrt{J_1'} \geq 0$$

for $J_1^* \leq Y_{10}$

$$f_2 (J_1^*, \sqrt{J_2'}^*) = Y_{16} - \sqrt{J_2'}^* \geq 0.$$

(NPL = 1, ITYPE = 2) This perfectly plastic yield surface is the same as that used with the cap. Cap is not used. Anisotropy is not recommended, $J_1^* = J_1$ and $J_2'^* = J_2'$; hence, Y_1 through $Y_9 = 0$.

The perfectly plastic yield criterion is prescribed by

for $J_1 > Y_{10}$

$$f_1 = Y_{11} \left(1 - \left|1 - \frac{J_1}{Y_{10}}\right|^2\right) + Y_{12} - \sqrt{J_2'} \geq 0$$

for $J_1 \leq Y_{10}$

$$f_1 = Y_{11} + Y_{12} - \sqrt{J_2'} \geq 0$$

Case 2
(NPL = 2, ITYPE = 2)

Cap model for rock. Perfectly plastic yield criterion is the same as that given above for NPL = 1, ITYPE = 2. In addition a cap is prescribed by

$$f_2 = (J_1 - V)^2 + P^2 (J_2' - Q) = 0$$

where

$$V = L + P^2 \chi (L) X' (L)$$

$$Q = [X(L)]^2 \{1 + P^2 [X'(L)]^2\}$$

for $L \leq Y_{10}$

$$X(L) = Y_{11} (1 - [1 - \frac{L}{Y_{10}}]^2 + Y_{12}$$

$$X'(L) = \frac{2Y_{11}}{Y_{10}} (1 - L/Y_{10})$$

for $L > Y_{10}$

$$X(L) = Y_{11} + Y_{12}$$

$$X'(L) = 0.$$

and

$$L = Y_{13} \int_o^t \left(1 - \frac{\sqrt{J_2'}}{\sqrt{J_2'} - f_1}\right)^2 \sqrt{I_2^P} \, dt$$

$$P = Y_{14}$$

For Cases 1 and 2.

COEFF(N,76) = Y_1

COEFF(N,77) = Y_2

COEFF(N,78) = Y_3

COEFF(N,79) = Y_4

COEFF(N,80) = Y_5

COEFF(N,81) = Y_6

COEFF(N,82) = Y_7

COEFF(N,83) = Y_8

COEFF(N,84) = Y_9

COEFF(N,85) = Y_{10}

COEFF(N,86) = Y_{11}

COEFF(N,87) = Y_{12}

COEFF(N,88) = Y_{13}

COEFF(N,89) = Y_{14}

COEFF(N,90) = Y_{15}

COEFF(N,91) = Y_{16}

COEFF(N,92) through COEFF(N,94) not used.

COEFF(N,95) = ITYPE

COEFF(N,96) through COEFF(N,100) not used.

Case 3
(NPL = 1, NVISC = 1)

(Viscoplasticity. May be used only with isotropic moduli and an isotropic perfectly plastic yield criterion of the type described in Case 1 (ITYPE ≠ 2) above.

for $J_1 > Y_{10}$

$$f_1 (J_1, J_2') = Y_{11} + Y_{12}J_1 + Y_{13}J_1^2 + Y_{14}J_1^3 - J_2' \geq 0$$

for $J_1 \leq Y_{10}$

$$f_1 (J_1, J_2') = Y_{16} - J_2' \geq 0$$

The viscoplastic strain rate is given by

$$\dot{\varepsilon}_{ij}^{P'} = Y_{17}\, \phi(f_1)\, \frac{\partial f}{\partial \sigma_{ij}}$$

for Case 3

COEFF(N,76) through COEFF(N,84) = 1.0

COEFF(N,85) = Y_{10}

COEFF(N,86) = Y_{11}

COEFF(N,87) = Y_{12}

COEFF(N,88) = Y_{13}

COEFF(N,89) = Y_{14}

COEFF(N,90) = Y_{15}

COEFF(N,91) = Y_{16}

COEFF(N,92) = Y_{17}

COEFF(N,93) through COEFF(N,100) are not used.

Case 4
(N1SO = 2, NVM = 1)

(Anisotropic fracture criterion of Jaeger which may be used with anisotropic variable moduli. May be used with plane geometry only. The fracture criterion is

$$(\sigma_1 - \sigma_3) - \frac{2a_o - 2Y_{14}\sigma_3}{Y_{14} - \sqrt{Y_{14}^2 + 1}} \leq 0$$

The coefficients a_o and a_1 are functions of fracture parameters which are submitted through YCOF. The appropriate parameters are selected by referring to two angles as follows:

BETA (computed internally) = CCW angle from direction of major principal stress to the direction of the bedding planes.

PSI = BCOF(40) = Orientation of BETA at which a_o is a minimum. Usually assumed to be 30^o (expressed in radians).

Principal directions of anisotropy are submitted through direction cosines in BCOF.

For $0 < PSI < BETA$

$$a_o = Y_{11} - Y_{12}\,[\cos 2\,(PSI - BETA)]^{Y_{13}}$$

For $BETA < PSI < 90^o$

$$a_o = Y_{17} - Y_{18}\,[\cos 2\,(PSI - BETA)]^{Y_{19}}$$

For Case 4

COEFF(N,76) through COEFF(N,84) = 1.0

COEFF(N,85) is not used.

COEFF(N,86) = Y_{11}

COEFF(N,87) = Y_{12}

COEFF(N,88) = Y_{13}

COEFF(N,88) = Y_{14}

COEFF(N,89), COEFF(N,90) are not used

COEFF(N,91) = Y_{17}

COEFF(N,92) = Y_{18}

COEFF(N,93) = Y_{19}

COEFF(N,94) through COEFF(N,100) are not used

Case 5
(NVISC = 2)

(Viscoelasticity. May be used only with isotropic moduli. Kelvin and Maxwell elements are available. Creep may be specified either in volumetric strain or in shear strain or in both simultaneously depending on the values of NVOL and NDEV.

Kelvin Element

$$\varepsilon^c_{t+\Delta t} = \varepsilon^c_t \exp(-a_1 \Delta t) + \sigma_t \frac{a_2}{a_1} (1 - \exp(-a_1 \Delta t))$$

creep in volumetric strain (NVOL = 3)

$$a_1 = \frac{K}{\eta_{bulk}} = Y_4$$

$$a_2 = \frac{1}{\eta_{bulk}} = Y_5$$

creep in shear strain (NDEV = 3)

$$a_1 = \frac{G}{\eta_{shear}} = Y_7$$

$$a_2 = \frac{1}{\eta_{shear}} = Y_8$$

Maxwell Element

$$\varepsilon_{t+\Delta t} = \varepsilon^c_t + (a_2\Delta t + a_1)\sigma_{t+\Delta t} - a_1\sigma_t$$

creep volumetric strain (NVOL = 2)

$$a_1 = \frac{1}{K} = 1/COEFF(1,N)$$

$$a_2 = \eta_{bulk} = Y_3$$

creep in shear strain (NDEV = 2)

$$a_1 = 1/G = 1/COEFF(2,N)$$

$$a_2 = \eta_{shear} = Y_6$$

3-Parameter Fluid

$$\varepsilon^c_{t+\Delta t} = \varepsilon^c_t + a_1\dot{\varepsilon}_t + a_2\sigma + a_3\dot{\sigma}$$

creep in bulk (NVOL = 1)

$$a_1 = \frac{\eta_{2bulk}}{K}\left[1 - \exp\left(-\frac{K}{\eta_{2bulk}}\Delta t\right)\right]$$

$$a_2 = \frac{1}{\eta_{1bulk}}\left[\Delta t - \frac{\eta_{2bulk}}{K}\left(1 - \exp\left(-\frac{K}{\eta_{2bulk}}\Delta t\right)\right)\right]$$

$$a_3 = \frac{\eta_{1bulk} + \eta_{2bulk}}{\eta_{1bulk} K}\left[\Delta t - \frac{\eta_{2bulk}}{K}\left(1 - \exp\left(-\frac{K}{\eta_{2bulk}}\Delta t\right)\right)\right]$$

$$\frac{K}{\eta_{2bulk}} = Y_3$$

$$\frac{1}{\eta_{1bulk}} = Y_4$$

$$\frac{1}{\eta_{2bulk}} = Y_5$$

creep in shear (NDEV = 1)

$$a_1 = \frac{\eta_{2shear}}{G}\left[1 - \exp\left(-\frac{G}{\eta_{2shear}}\Delta t\right)\right]$$

$$a_2 = \frac{1}{\eta_{1shear}}\left[\Delta t - \frac{\eta_{2shear}}{G}\left(1 - \exp\left(-\frac{G}{\eta_{2shear}}\Delta t\right)\right)\right]$$

$$a_3 = \frac{\eta_{1shear} + \eta_{2shear}}{\eta_{1shear} G}\left[\Delta t - \frac{\eta_{2shear}}{G}\left(1 - \exp\left(\frac{G}{\eta_{2shear}}\Delta t\right)\right)\right]$$

$$\frac{G}{\eta_{2shear}} = Y_6$$

$$\frac{1}{\eta_{1shear}} = Y_7$$

$$\frac{1}{\eta_{2shear}} = Y_8$$

For Case 5

COEFF(N,76), COEFF(N,77) not used

COEFF(N,78) = Y_3

COEFF(N,79) = Y_4

COEFF(N,80) = Y_5

COEFF(N,81) = Y_6

COEFF(N,82) = Y_7

COEFF(N,83) = Y_8

COEFF(N,84) through COEFF(N,100) not used.

APPENDIX C

FILE USAGE

Logical Unit Number	Name	Contents and Description
9	LINK	1. Link tape contains data on the problem size, loading and material properties.

Record 1 (38 words) -
- IWHDR(20) - run title
- IWNNP - number of nodes
- IWNEL - number of elements
- IWNMAT - number of materials
- IWBAND - bandwidth
- IWNEQ - number of equations
- MAXSTP - number of live loads
- NLDI - number of dead load increments
- IRELT - number output/deadload flag
- NTYPE(10) - number of elements of each type

Record 2 (6*IWNNP) - ID array (relates node points to degrees of freedom)

Record 3 (3*IWNNP) - Load coefficients

Record 4 (4-MAXSTP) - Live loads-Time, P_x, P_y, P_z

Record 5 (100*IWNMAT) - Material properties

2. On restarted runs, the previously generated restart tape is mounted as LINK, and all other files remain as before.

Logical Unit Number	Name	Contents and Description
11	LEU	Element data tape contains one record for each element. All records are the same size, which is the maximum length required for the elements which are present (see appendix D for complete description of each element).
13	LOUT	Output data tape.

Record 1 (22 words) -
- IWHDR(20) - run title
- IWNNP - number of nodes
- iWNEL - number of elements

Record 2 (6*IWNNP) - ID array relating nodes to degrees of freedom

Record 3 (4 words) -
- IWBAND - bandwidth
- iWNEQ - total DOFs
- IWNEQB - DOFs/block
- NBLOCK - number of blocks

Records 4 - N contain output data for each load step, written as required. Each record is IWNEQB+2 or 23 words long, whichever is greater. The first words of a record contains the time corresponding to this load step and word 2 is a signal whether the record is displacement data (if = 0) or element data (= number of elements in the block). If the record is an element record, each element consists of:

1. element number
2. element type
3. yield factor
4. stress (6 words)
5. strain (12 words)

Element data is packed 21 words at a time into an output block.

Logical Unit Number	Name	Contents and Description
7 12 14	LRST1 LFK1 LFK0	These files are used alternately (as required by the whims of the code) to contain: 1) the global stiffness, written as NBLOCK+1 records of IWBAND* NEQB words or 2) Restart data. If restart is used, the file must hold: 1. 65 words of common data 2. 70 words of control data 3. 20 words of array addresses 4. Live load and material properties (4*MAXSTP and 100* IWMAT words) 5. Global stiffness (IWBAND*NEQB) } NBLOCK 6. Load/displacement (IWNCF*NEQB) } sets 7. Stress history (≤ 248 words/element, IWNEL records) 8. Load coefficients (3* number of loaded Nodes + 1
20 21	LSTR1 LSTR0	Stress history data, written 1 record per element (at most 248 words/element)
†38 †39	LFIN LFOUT	Contain the force vector, total displacement, and incremental displacement. NBLOCK + 1 records IWNCF*IWNEQB long
40	LOAD	Load coefficients, three words for each loaded node, written in blocks of NLDB nodes
†41 †42	LTMP1 LTMP2	Contain element stiffness data which overflow global stiffness blocks. At most 325 words per record, < NUMEL records
†43 †44	LTP1 LTP2	Used by DECOMP to store terms which overflow to stiffness blocks. Requires at most $IWBAND^2$ + NEQ words

†These files are not needed for a core contained (NBLOCK = 1) problem

APPENDIX D

CONTENTS OF ELEMENT TAPE

For all elements

		Length, words
IB (1)	= Element number	1
IB (2)	= Element type	1
IB (3)	= Step element becomes active	1
IB (4)	= Step element goes inactive	1
IB (5)	= Minimum DOF for this element	1
IB (6)	= Maximum DOF for this element	1
IB (7)	= Material number	1
IB (8)-IB (11)	= Volume of element*	4
IB (12)	= (Not used)	1
IB (13)-IB (21)	= Direction cosines	9

This part of the data is constant for all elements. Format for remaining data is similar for each element.

The LM array always starts at IB (LMSTRT + 1)

Dead loads always start at IB (ND + LMSTRT + 1)

B-matrix always starts at IB (2 * ND+LMSTRT + 1)

LMSTRT is presently set to 21.

Following the B-matrix are data for slip elements.

*IB (8)-IB (11) contain partial volumes for axisymmetric elements. IB (8) contains total volume for all others.

Element Type ±1 1-D Bar ND = 6

			Length
IB (22)	-	DOF X_1	6
23	-	DOF X_2	
24	-	DOF Y_1	
25	-	DOF Y_2	
26	-	DOF Z_1	
27	-	DOF Z_2	
IB (28)	-	X_1 dead load	6
29	-	X_2 dead load	
30	-	Y_1 dead load	
31	-	Y_2 dead load	
32	-	Z_1 dead load	
33	-	Z_2 dead load	
IB (34) - (39)		[B] matrix (6 x 1)	6
IB (40 - 45)		[B] matrix at center of element	6
IB (46)		initial stress	1

Element Type 2 Beam ND = 12

			Length
IB (22-33)	-	DOF's $X_1, Y_1, Z_1, \theta_{X_i}, \theta_{Y_i}, \theta_{Z_1}$ $X_2, Y_2, Z_2, \theta_{X_2}, \theta_{Y_2}, \theta_{Z_2}$	12
IB (34-45)	-	Dead load components corresponding to DOF's	12
IB (46-189)	-	Force-displacement transform	144
IB (190-267)	-	Element stiffness [k]	

Element Type ±3, 4 2-D Quad or Axisym ND = 8

		Length
IB (22-29)	DOF's	
	X_1, X_2, X_3, X_4, Y_1, Y_2, Y_3, Y_4	8
IB (30-37)	Dead load components	8
IB (38-109)	[B] matrix as 3 x 24	72
IB (110-127)	[B] at center of element as 3 x 6	18

Element Type 5 3-D Brick ND = 24

IB (22-45)	DOF's	24
	X_i i = 1, 8	
	Y_i i = 1, 8	
	Z_i i = 1, 8	
IB (46-69)	Dead load components	24
IB (70-333)	[B] matrix, or 3 x 11 x 8	288
IB (334-366)	[B] at element center	33

Element Type 6 Thick Shell ND = 48

		Length
IB (22-69)	NDOF's	48
	(X_i, Y_i, Z_i) i = 1, 16	
IB (70-117)	Dead load components	48
IB (118-405)	ε-u transform, or 6 x 48	288

Each thick shell element record is followed by five records containing [k] for the element:

IB (1)	Highest DOF for this group, ND1	1
IB (2-(ND1 + 1))	DOF's	ND1
IB ((ND1 + 2)-325)	Rows of [k]	

The first four records each contain six rows of [k], with the last 24 rows in record 5.

Values of ND1 for the five records are

record	ND1
1	48
2	42
3	36
4	30
5	24

Element Types 7 and 9 2-D or Axisym w/slip ND = 12

		Length
IB (22-29)	DOF's for parent element $X_1, X_2, X_3, X_4, Y_1, Y_2, Y_3, Y_4$	8
IB (30-33)	DOF's on adjoining slip	4
IB (34-41)	Dead loads on parent element	8
IB (42-45)	Dead loads on adjoining slip	4
IB (46-117)	[B] for parent element	72
IB (118-135)	[B] at center of parent	18
IB (136)	Face number of slip element	1
IB (137)	Material number of slip	1
IB (138-141)	Coordinates of slip surface X_1, X_2, Y_1, Y_2	4
IB (146)	Slip thickness	1

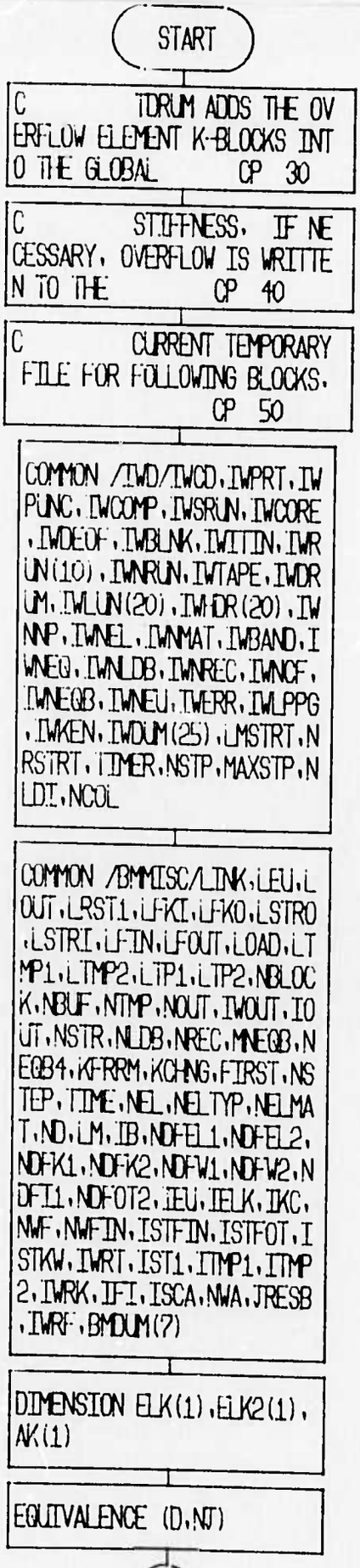
Element Type 8 3-D with Slip* ND = 36

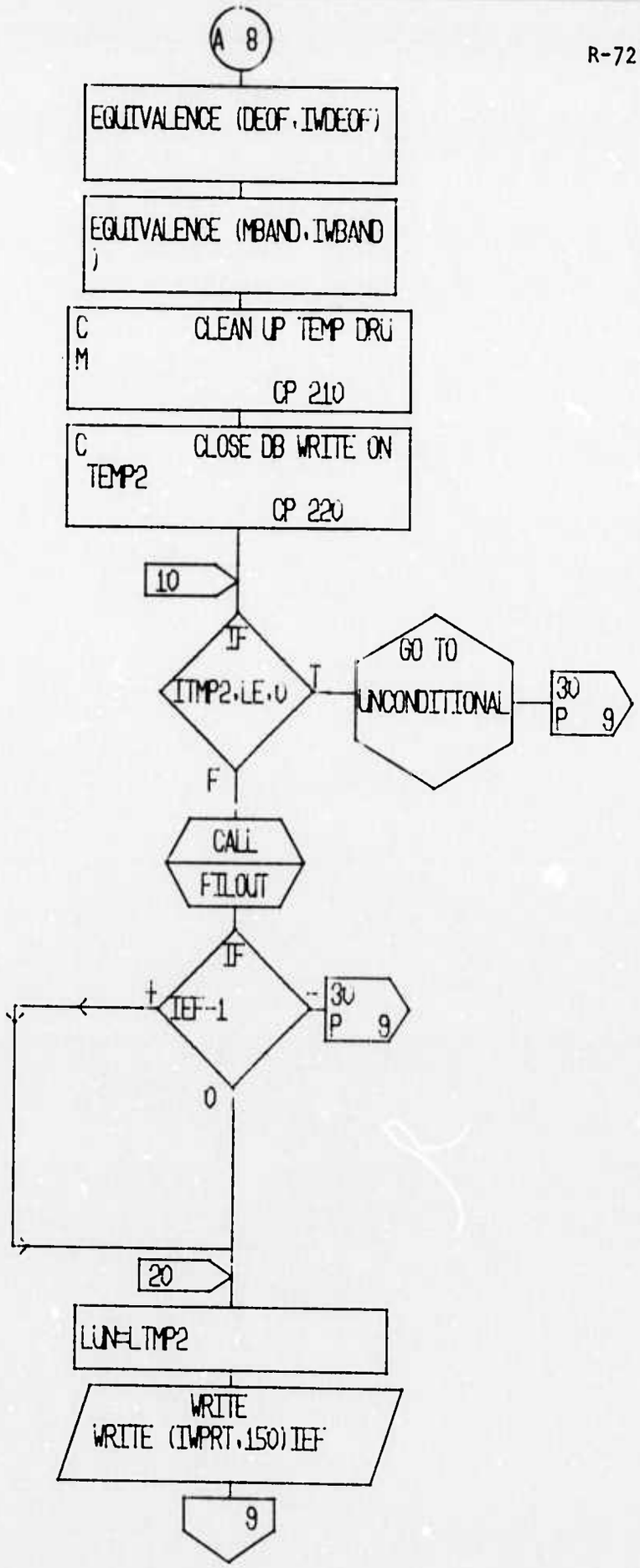
		Length
IB (12-45)	DOF's for parent	24
	X_i, i = 1, 8	
	Y_i, i = 1, 8	
	Z_i, i = 1, 8	
IB (46-57)	DOF's for slip surface	12
IB (58-81)	Dead local components for parent	24
IB (83-93)	Dead load components for slip	12
IB (94-357)	B matrix for parent	288
IB (358-390)	B at center of parent	33
IB (391)	Face number	1
IB (392)	Material number	1
IB (393-404)	Coordinates of slip	12
IB (405)	Thickness	1

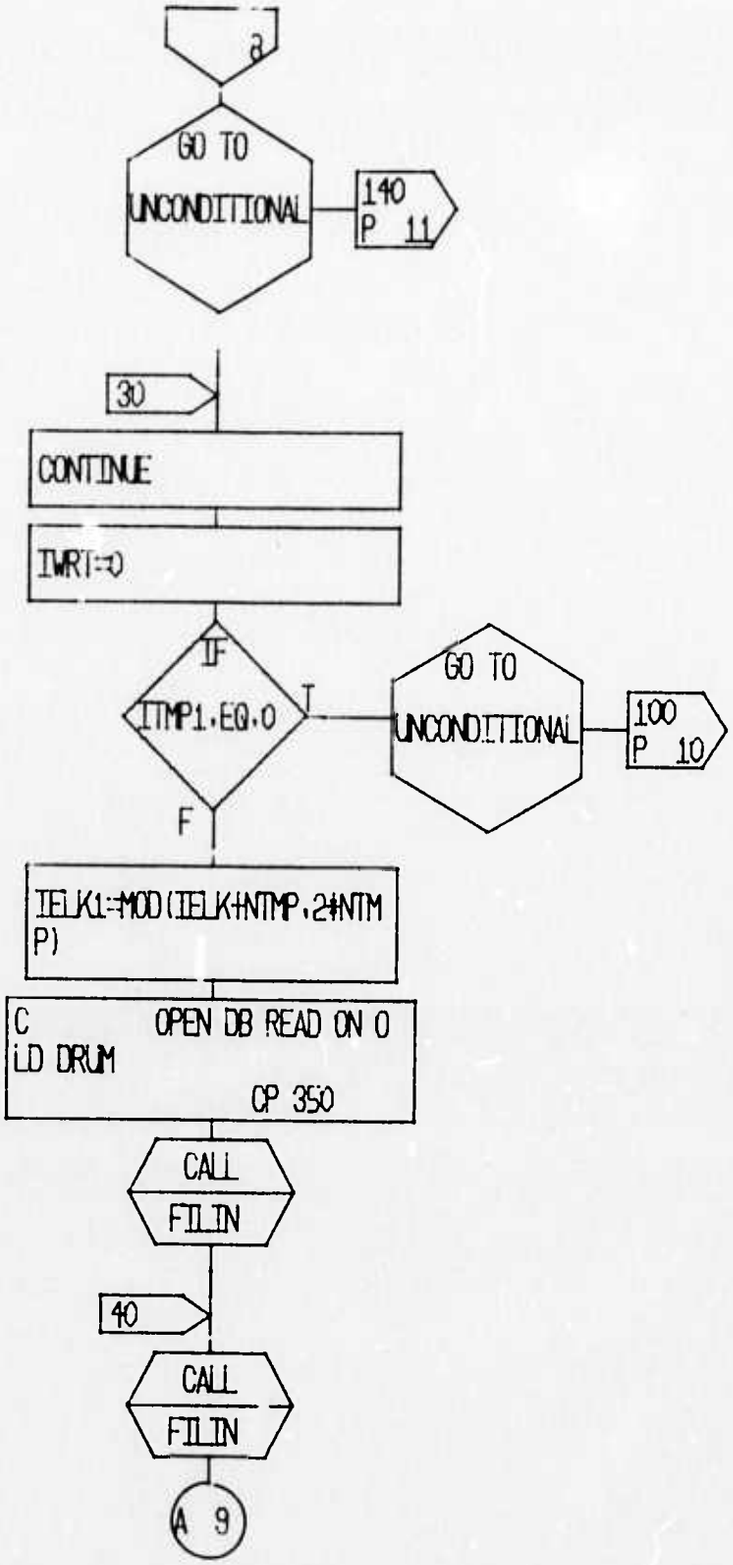
*Not implemented

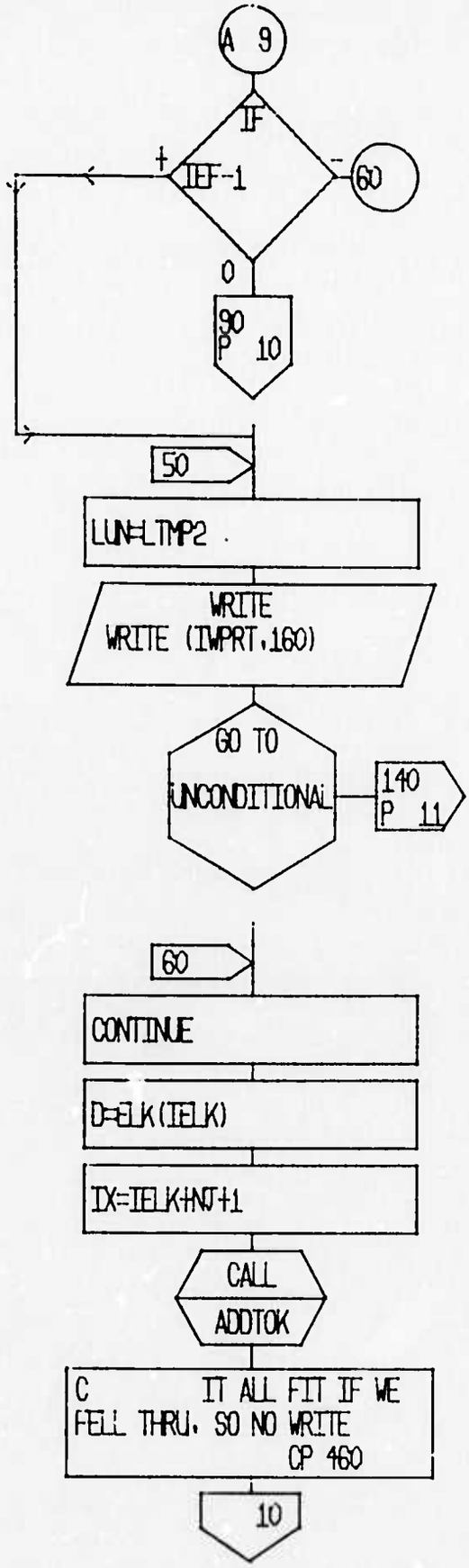
APPENDIX E

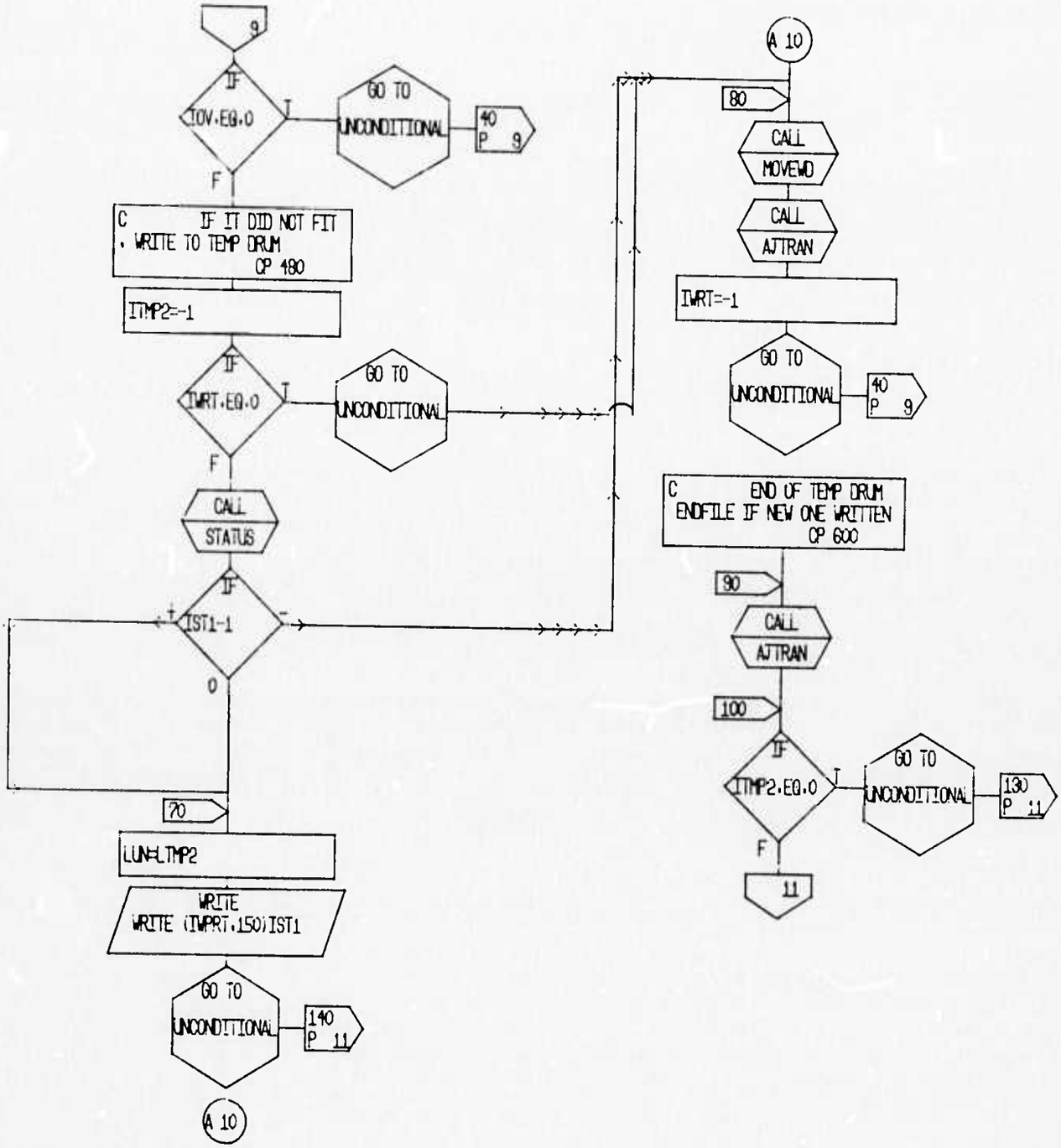
FLOW CHART OF SUBROUTINE TDRUM-- PROCESS ELEMENT STIFFNESS WHICH OVERFLOWED PREVIOUS GLOBAL STIFFNESS BLOCKS

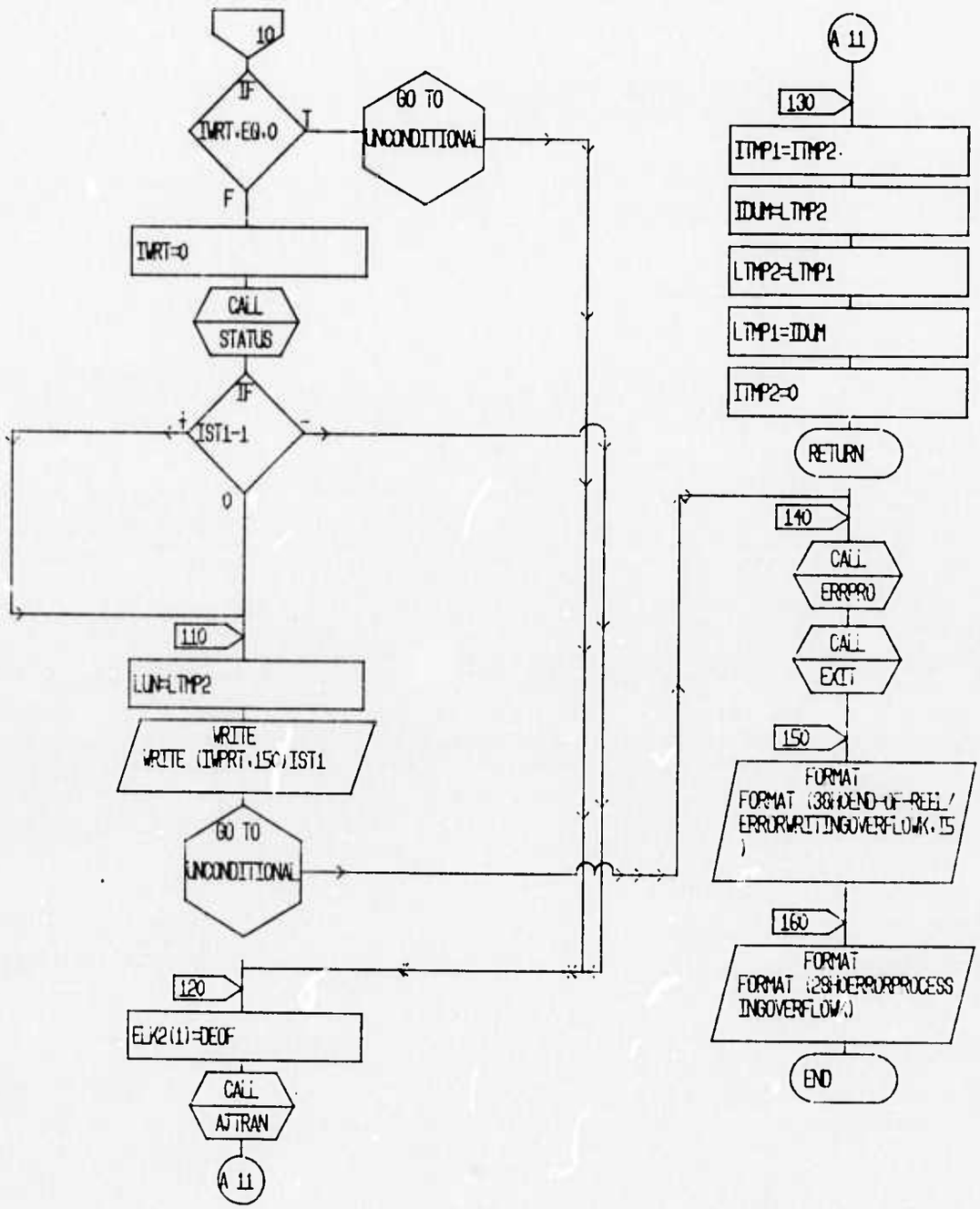

START
C TDRUM ADDS THE OVERFLOW ELEMENT K-BLOCKS INTO THE GLOBAL CP 30
C STIFFNESS. IF NECESSARY, OVERFLOW IS WRITTEN TO THE CP 40
C CURRENT TEMPORARY FILE FOR FOLLOWING BLOCKS. CP 50
COMMON /IWD/IWCD,IWPRT,IWPUNC,IWCOMP,IWSRUN,IWCORE,IWDEOF,IWBLNK,IWITIN,IWRUN(10),IWNRUN,IWTAPE,IWDRUM,IWLUN(20),IWHDR(20),IWNNP,IWNEL,IWNMAT,IWBAND,IWNEQ,IWNLDB,IWNREC,IWNCF,IWNEQB,IWNEU,IWERR,IWLPPG,IWKEN,IWDUM(25),LMSTRT,NRSTRT,ITIMER,NSTP,MAXSTP,NLDI,NCOL
COMMON /BMMISC/LINK,LEU,LOUT,LRST1,LFKI,LFKO,LSTRO,LSTRI,LFIN,LFOUT,LOAD,LTMP1,LTMP2,LTP1,LTP2,NBLOCK,NBUF,NTMP,NOUT,IWOUT,IOUT,NSTR,NLDB,NREC,MNEQB,NEQB4,KFRRM,KCHNG,FIRST,NSTEP,TIME,NEL,NELTYP,NELMAT,ND,LM,IB,NDFEL1,NDFEL2,NDFK1,NDFK2,NDFW1,NDFW2,NDFT1,NDFOT2,IEU,IELK,IKC,NWF,NWFIN,ISTFIN,ISTFOT,ISTKW,IWRT,IST1,ITMP1,ITMP2,IWRK,IFI,ISCA,NWA,JRESB,IWRF,BMDUM(7)
DIMENSION ELK(1),ELK2(1),AK(1)
EQUIVALENCE (D,NJ)
A 8


A 8
EQUIVALENCE (DEOF,IWDEOF)
EQUIVALENCE (MBAND,IWBAND
)
C CLEAN UP TEMP DRU
M
CP 210
C CLOSE DB WRITE ON
TEMP2
CP 220
10
IF
ITMP2.LE.0
T
GO TO
UNCONDITIONAL
30
P 9
F
CALL
FILOUT
IF
IEF-1
+
-
30
P 9
0
20
LUN=LTMP2
WRITE
WRITE (IWPRT,150)IEF
9


a
GO TO
UNCONDITIONAL
140
P 11
30
CONTINUE
IWRT=0
IF
ITMP1.EQ.0
T
GO TO
UNCONDITIONAL
100
P 10
F
IELK1=MOD(IELK+NTMP,2+NTM
P)
C OPEN DB READ ON 0
LD DRUM
OP 350
CALL
FILIN
40
CALL
FILIN
A 9

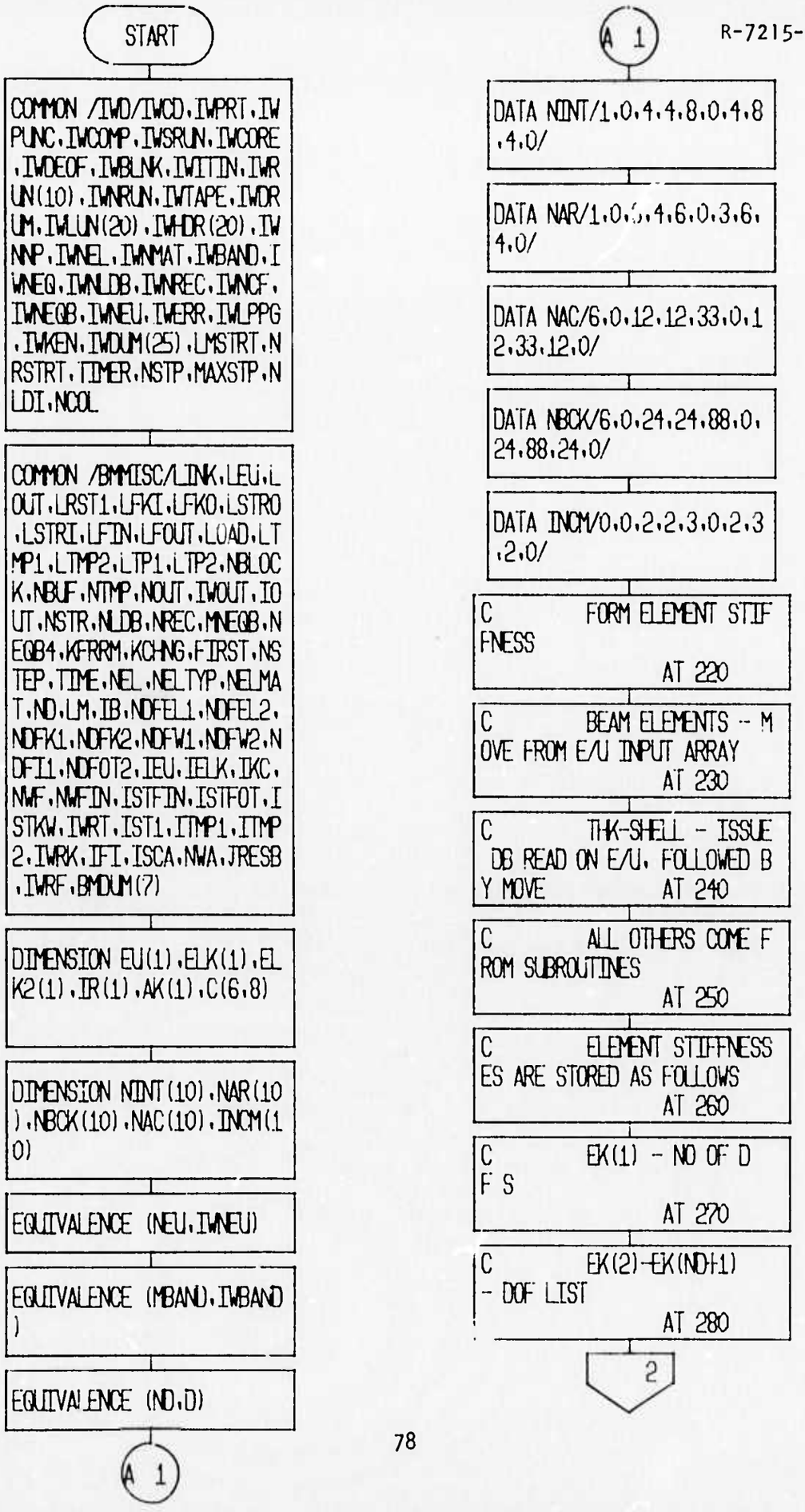

A 9
IF
IEF-1
+
-
60
0
90
P 10
50
LUN=LTMP2
WRITE
WRITE (IWPRT,160)
GO TO
UNCONDITIONAL
140
P 11
60
CONTINUE
D=ELK(IELK)
IX=IELK+NJ+1
CALL
ADDTOK
C IT ALL FIT IF WE
FELL THRU, SO NO WRITE
CP 460
10

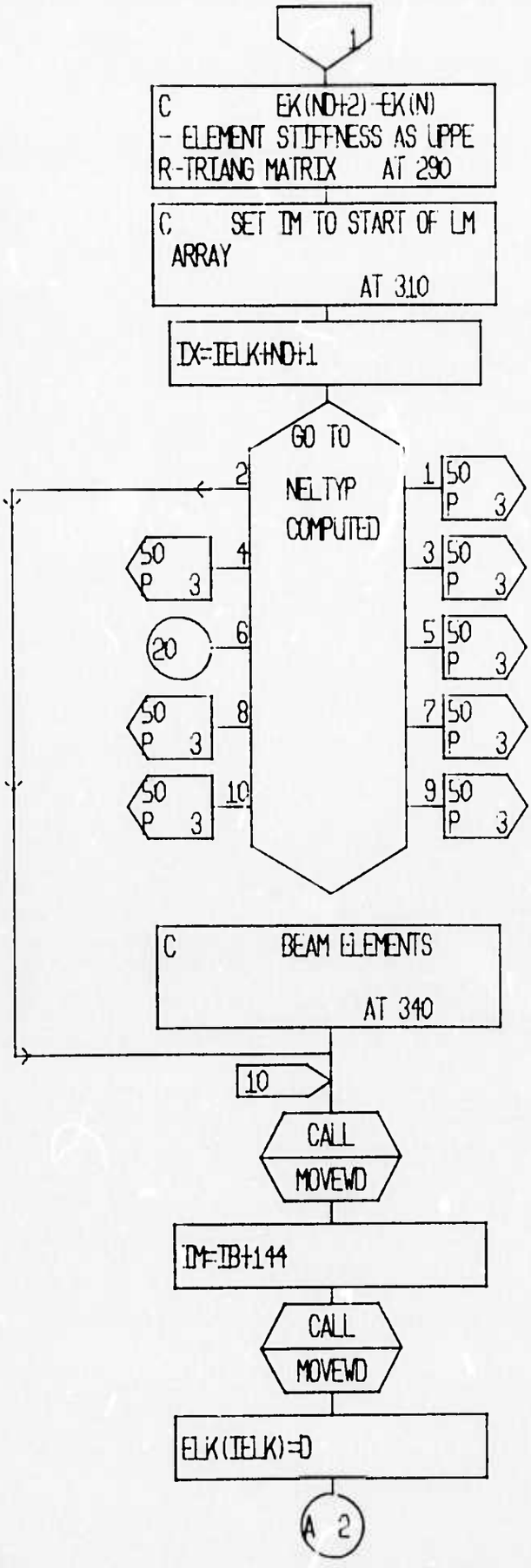

9
IF
IOV.EQ.0
I
GO TO
UNCONDITIONAL
40
P 9
F
C IF IT DID NOT FIT
, WRITE TO TEMP DRUM
OP 180
ITMP2=-1
IF
IWRT.EQ.0
I
GO TO
UNCONDITIONAL
F
CALL
STATUS
IF
IST1-1
+
-
0
70
LUN=LTMP2
WRITE
WRITE (IWRT,150)IST1
GO TO
UNCONDITIONAL
140
P 11
A 10
A 10
80
CALL
MOVEWD
CALL
AJTRAN
IWRT=-1
GO TO
UNCONDITIONAL
40
P 9
C END OF TEMP DRUM
ENDFILE IF NEW ONE WRITTEN
OP 600
90
CALL
AJTRAN
100
IF
ITMP2.EQ.0
I
GO TO
UNCONDITIONAL
130
P 11
F
11

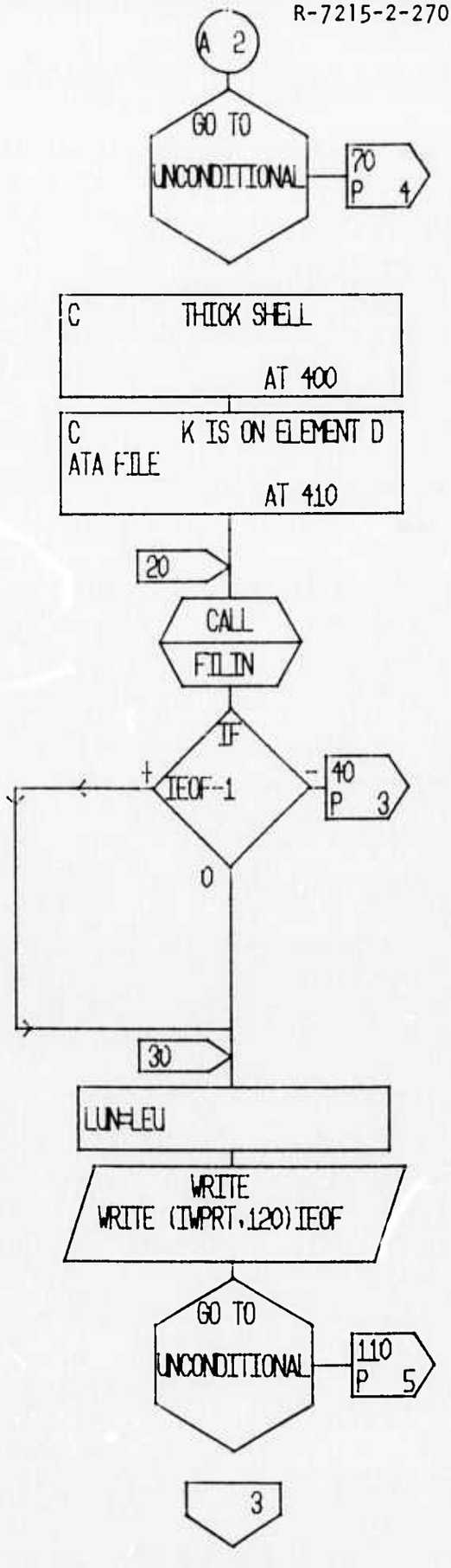

10
IF
IWRT.EQ.0
T
GO TO
UNCONDITIONAL
F
IWRT=0
CALL
STATUS
IF
IST1-1
-
+
0
110
LUN=LTMP2
WRITE
WRITE (IWPRT,150)IST1
GO TO
UNCONDITIONAL
120
ELK2(1)=DEOF
CALL
AJTRAN
A 11
A 11
130
ITMP1=ITMP2
IDUM=LTMP2
LTMP2=LTMP1
LTMP1=IDUM
ITMP2=0
RETURN
140
CALL
ERRPRO
CALL
EXIT
150
FORMAT
FORMAT (38HOEND-OF-REEL/
ERRORWRITINGOVERFLOWK,I5
)
160
FORMAT
FORMAT (28HOERRORPROCESS
INGOVERFLOWK)
END

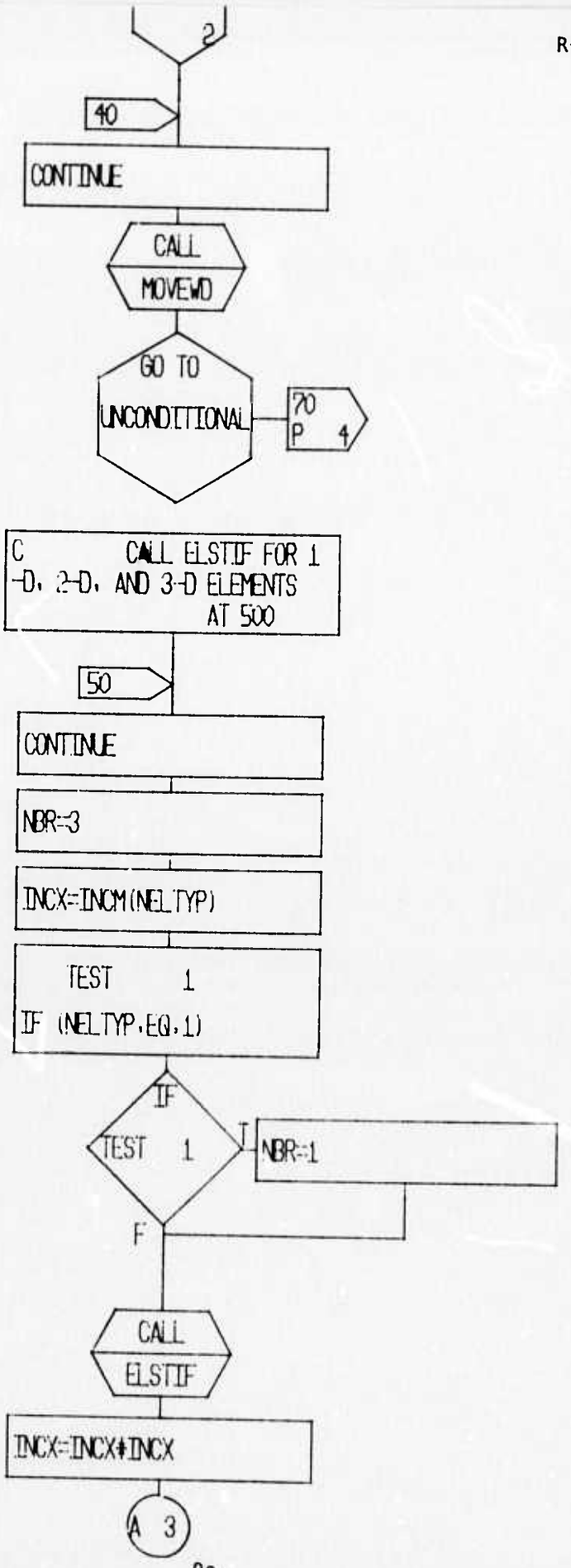
APPENDIX F

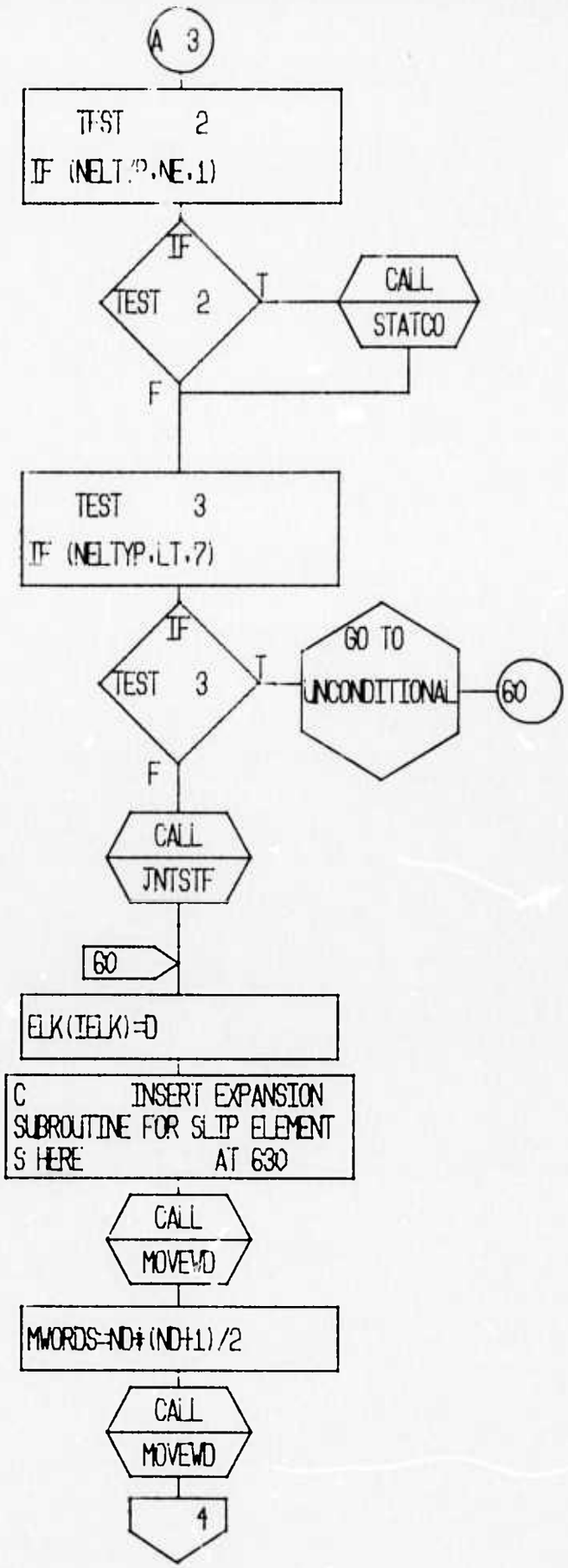
FLOW CHART OF SUBROUTINE BSTIF
ASSEMBLES GLOBAL STIFFNESS MATRIX

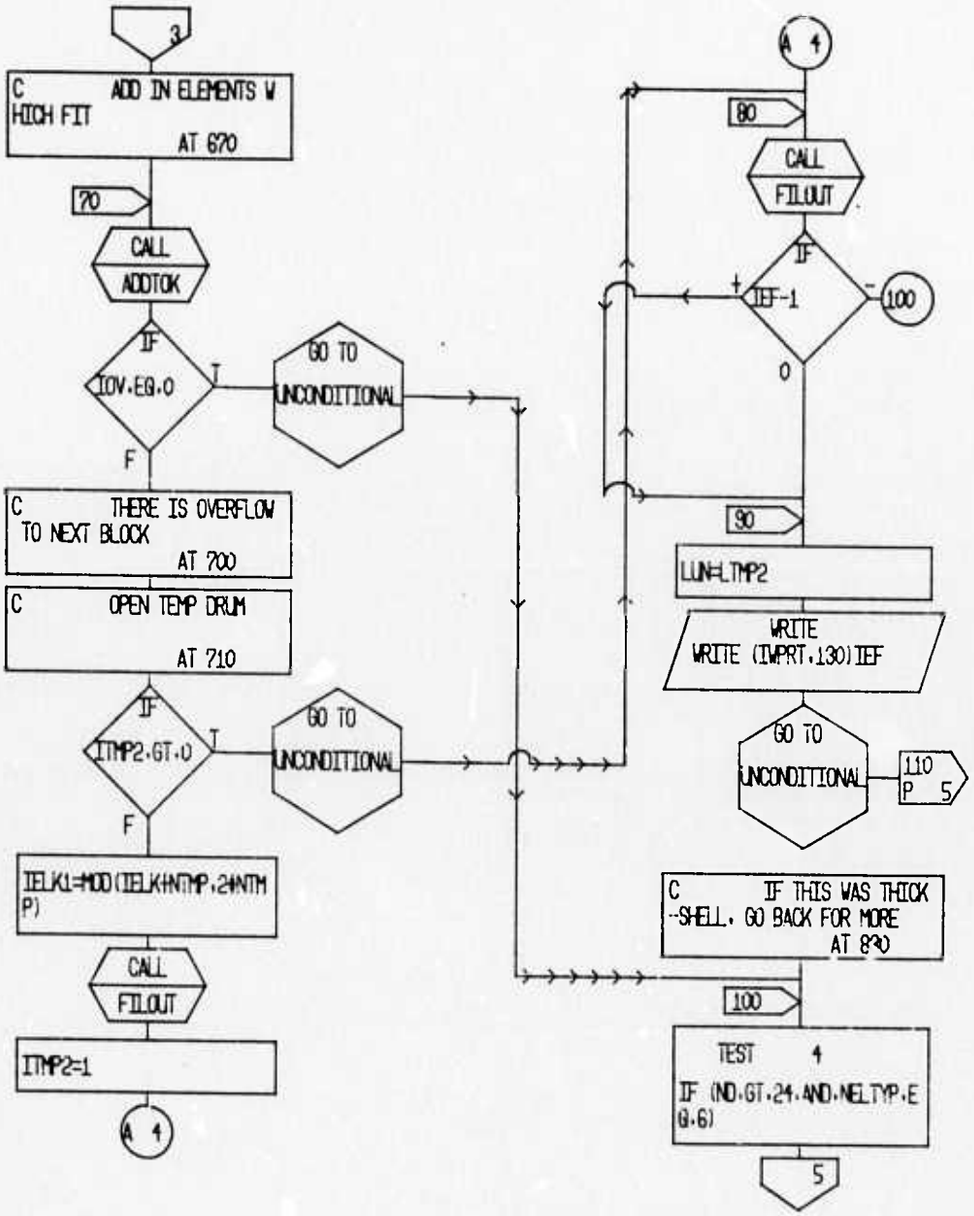

START
COMMON /IWD/IWCD,IWPRT,IWPUNC,IWCOMP,IWSRUN,IWCORE,IWDEOF,IWBLNK,IWITIN,IWRUN(10),IWNRUN,IWTAPE,IWDRUM,IWLUN(20),IWHDR(20),IWNNP,IWNEL,IWNMAT,IWBAND,IWNEQ,IWNLDB,IWNREC,IWNCF,IWNEQB,IWNEU,IWERR,IWLPPG,IWKEN,IWDUM(25),LMSTRT,NRSTRT,TIMER,NSTP,MAXSTP,NLDI,NCOL
COMMON /BMMISC/LINK,LEU,LOUT,LRST1,LFKI,LFKO,LSTRO,LSTRI,LFIN,LFOUT,LOAD,LTMP1,LTMP2,LTP1,LTP2,NBLOCK,NBUF,NTMP,NOUT,IWOUT,IOUT,NSTR,NLDB,NREC,MNEQB,NEQB4,KFRRM,KCHNG,FIRST,NSTEP,TIME,NEL,NELTYP,NELMAT,ND,LM,IB,NDFEL1,NDFEL2,NDFK1,NDFK2,NDFW1,NDFW2,NDFI1,NDFOT2,IEU,IELK,IKC,NWF,NWFIN,ISTFIN,ISTFOT,ISTKW,IWRT,IST1,ITMP1,ITMP2,IWRK,IFI,ISCA,NWA,JRESB,IWRF,BMDUM(7)
DIMENSION EU(1),ELK(1),ELK2(1),IR(1),AK(1),C(6,8)
DIMENSION NINT(10),NAR(10),NBCK(10),NAC(10),INCM(10)
EQUIVALENCE (NEU,IWNEU)
EQUIVALENCE (MBAND,IWBAND)
EQUIVALENCE (ND,D)
A 1
A 1
DATA NINT/1,0,4,4,8,0,4,8,4,0/
DATA NAR/1,0,6,4,6,0,3,6,4,0/
DATA NAC/6,0,12,12,33,0,12,33,12,0/
DATA NBCK/6,0,24,24,88,0,24,88,24,0/
DATA INCM/0,0,2,2,3,0,2,3,2,0/
C FORM ELEMENT STIFFNESS AT 220
C BEAM ELEMENTS -- MOVE FROM E/U INPUT ARRAY AT 230
C THK-SHELL - ISSUE DB READ ON E/U, FOLLOWED BY MOVE AT 240
C ALL OTHERS COME FROM SUBROUTINES AT 250
C ELEMENT STIFFNESSES ARE STORED AS FOLLOWS AT 260
C EK(1) - NO OF DFS AT 270
C EK(2)-EK(ND+1) - DOF LIST AT 280
2

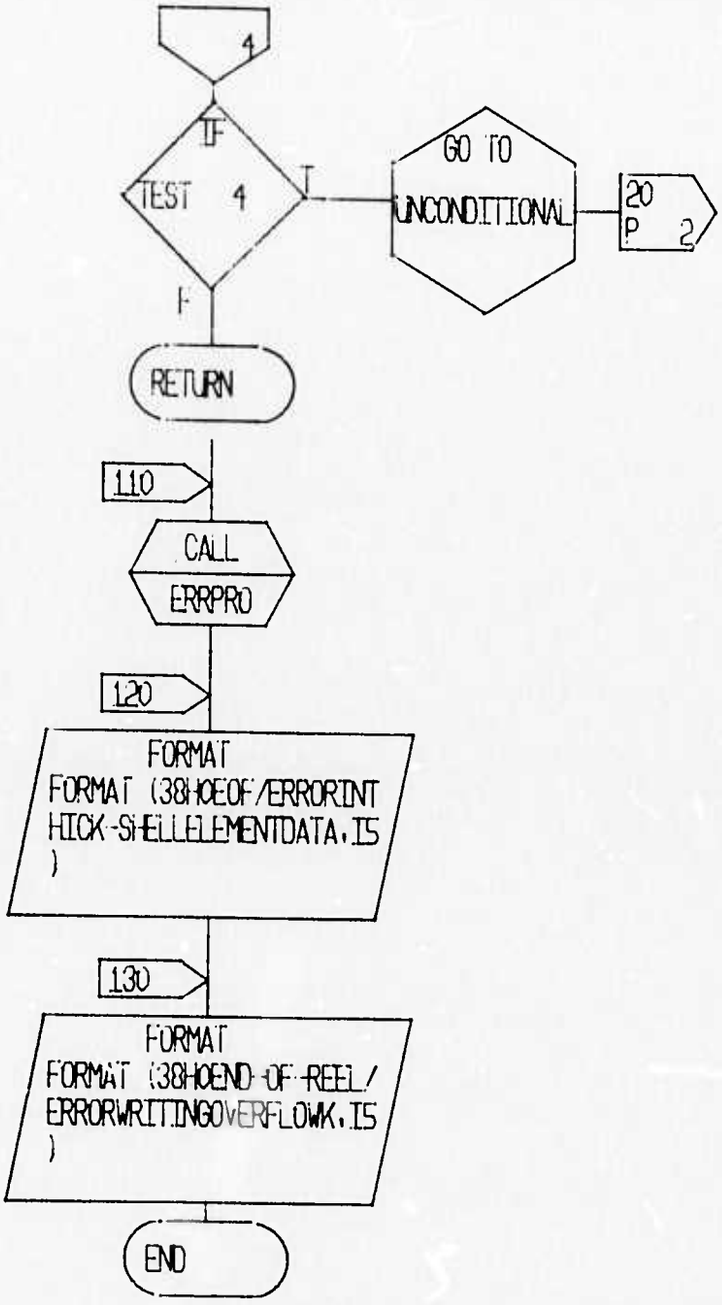

1
C EK(ND+2)=EK(N)
- ELEMENT STIFFNESS AS UPPE
R-TRIANG MATRIX AT 290
C SET IM TO START OF LM
ARRAY
AT 310
IX=IELK+ND+1
GO TO
NELTYP
COMPUTED
2
1
50
P 3
4
3
6
5
8
7
10
9
20
C BEAM ELEMENTS
AT 340
10
CALL
MOVEWD
IM=IB+144
CALL
MOVEWD
ELK(IELK)=0
A 2


A 2
GO TO
UNCONDITIONAL
70
P 4
C THICK SHELL
AT 400
C K IS ON ELEMENT D
ATA FILE
AT 410
20
CALL
FILIN
IF
+
IEOF-1
-
40
P 3
0
30
LUN=LEU
WRITE
WRITE (IWPRT,120)IEOF
GO TO
UNCONDITIONAL
110
P 5
3


2
40
CONTINUE
CALL
MOVEWD
GO TO
UNCONDITIONAL
70
P 4
C CALL ELSTIF FOR 1
-D, 2-D, AND 3-D ELEMENTS
AT 500
50
CONTINUE
NBR=3
INCX=INCM(NELTYP)
TEST 1
IF (NELTYP.EQ.1)
IF
TEST 1
T
NBR=1
F
CALL
ELSTIF
INCX=INCX+INCX
A 3

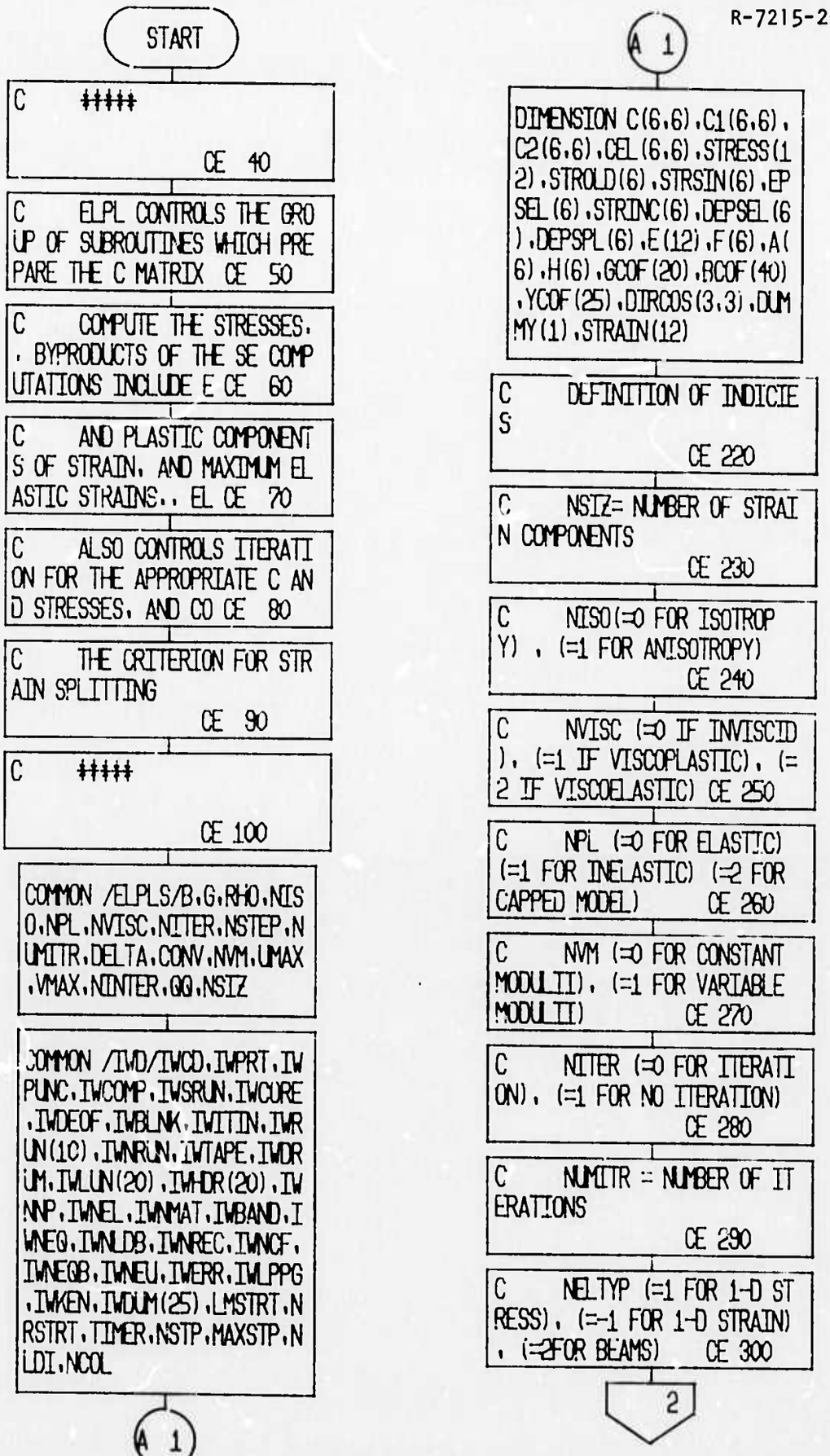

A 3
TEST 2
IF (NELTYP.NE.1)
IF TEST 2
T
CALL STATCO
F
TEST 3
IF (NELTYP.LT.7)
IF TEST 3
T
GO TO UNCONDITIONAL
60
F
CALL JNTSTF
60
ELK(IELK)=0
C INSERT EXPANSION SUBROUTINE FOR SLIP ELEMENT S HERE AT 630
CALL MOVEWD
MWORDS=ND*(ND+1)/2
CALL MOVEWD
4

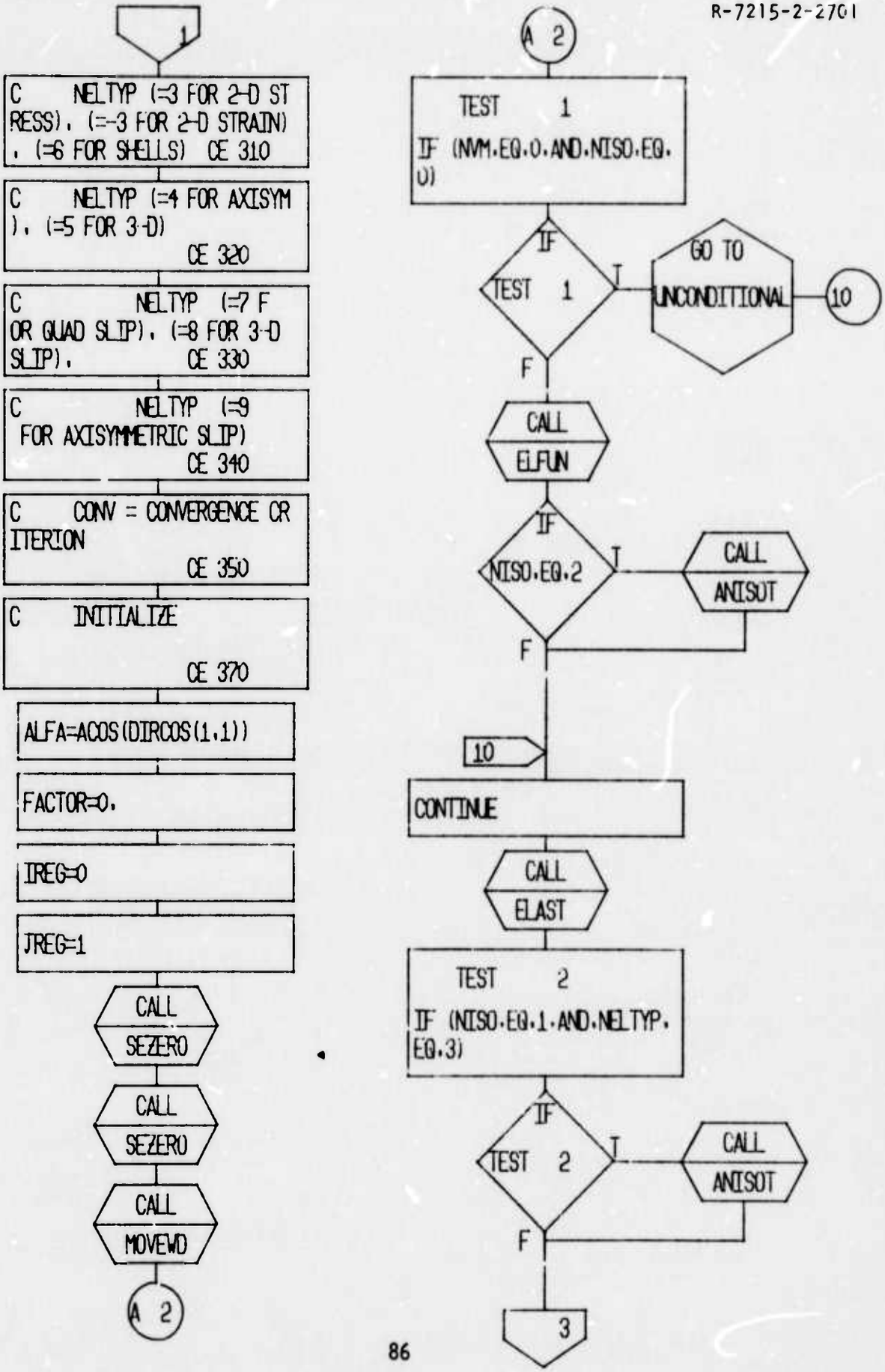

3
C ADD IN ELEMENTS W HICH FIT AT 670
70
CALL ADDTOK
IF IOV.EQ.0
T
GO TO UNCONDITIONAL
F
C THERE IS OVERFLOW TO NEXT BLOCK AT 700
C OPEN TEMP DRUM AT 710
IF ITMP2.GT.0
T
GO TO UNCONDITIONAL
F
IELK1=MOD(IELK+NTMP,24NTM P)
CALL FILOUT
ITMP2=1
A 1
A 1
80
CALL FILOUT
IF IEF-1
+
-
100
0
90
LUN=LTMP2
WRITE WRITE (IWPRT,130)IEF
GO TO UNCONDITIONAL
110 P 5
C IF THIS WAS THICK --SHELL, GO BACK FOR MORE AT 830
100
TEST 4
IF (ND.GT.24.AND.NELTYP.E Q.6)
5

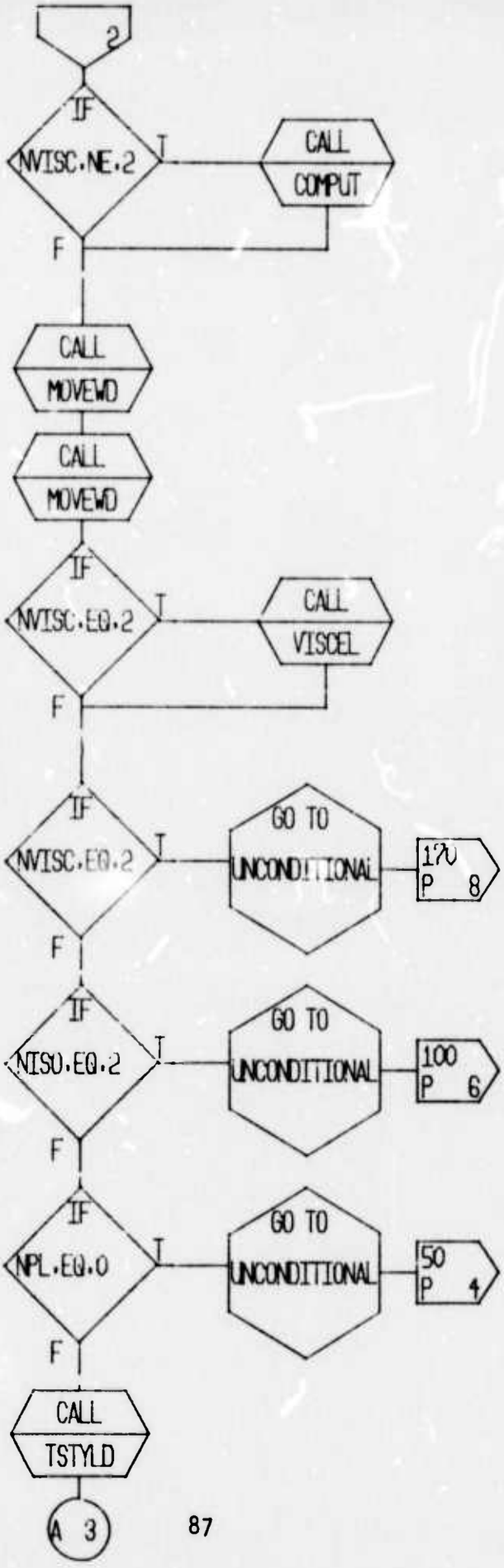

4
IF
TEST 4
T
GO TO
UNCONDITIONAL
20
P 2
F
RETURN
110
CALL
ERRPRO
120
FORMAT
FORMAT (38HOEOF/ERRORINT
HICK-SHELLELEMENTDATA,I5
)
130
FORMAT
FORMAT (38HOEND OF REEL/
ERRORWRITINGOVERFLOWK,I5
)
END

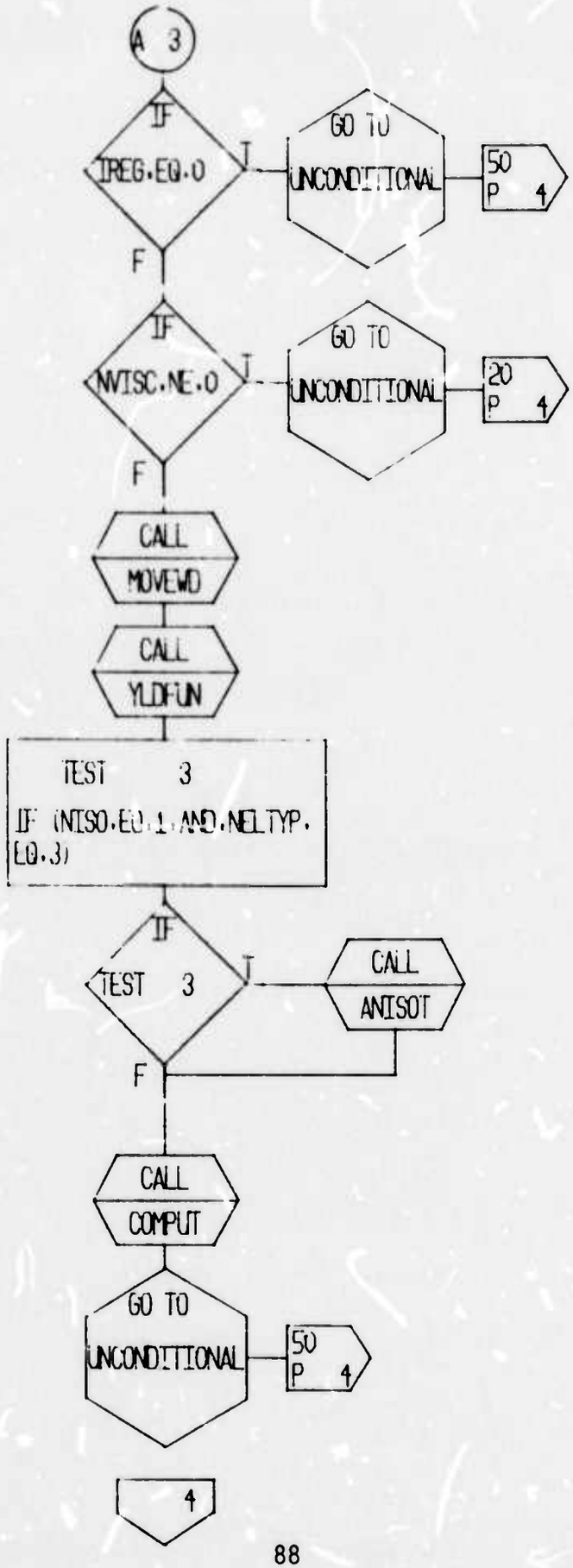
APPENDIX G

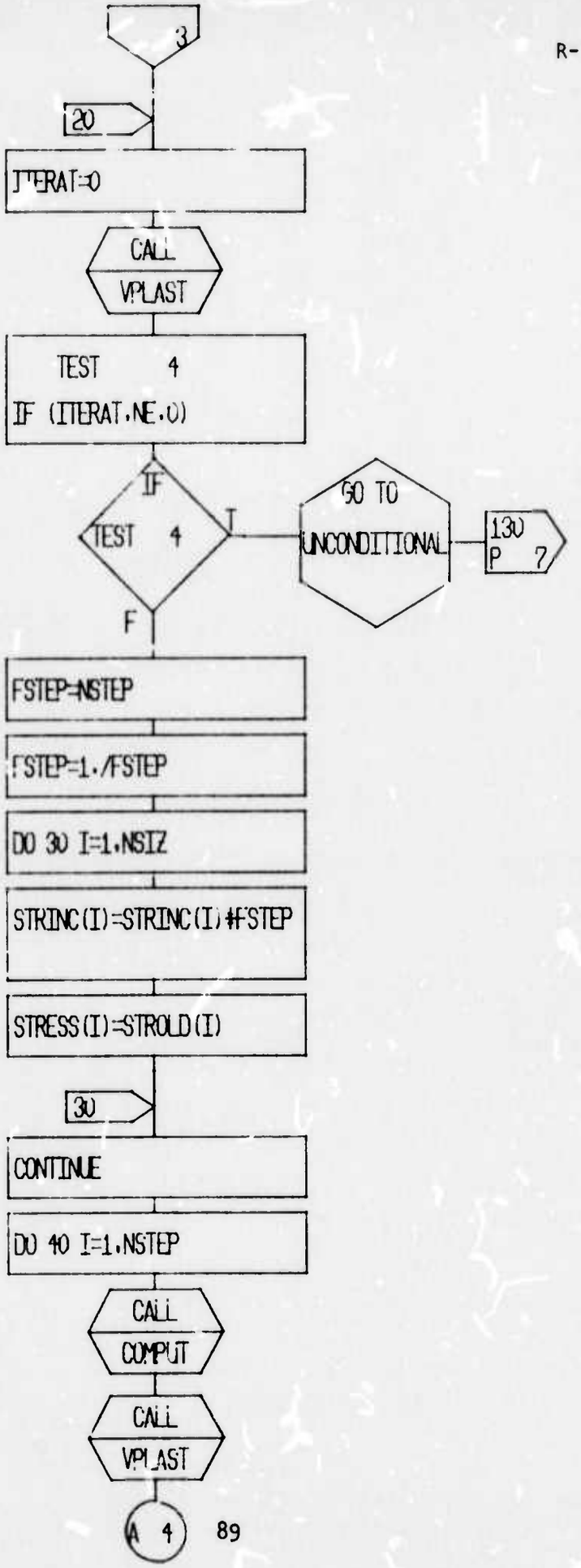
FLOW CHART OF SUBROUTINE ELPL--
COMPUTES GENERALIZED STRESS/STRAIN RELATIONS
AND COMPUTES STRESSES

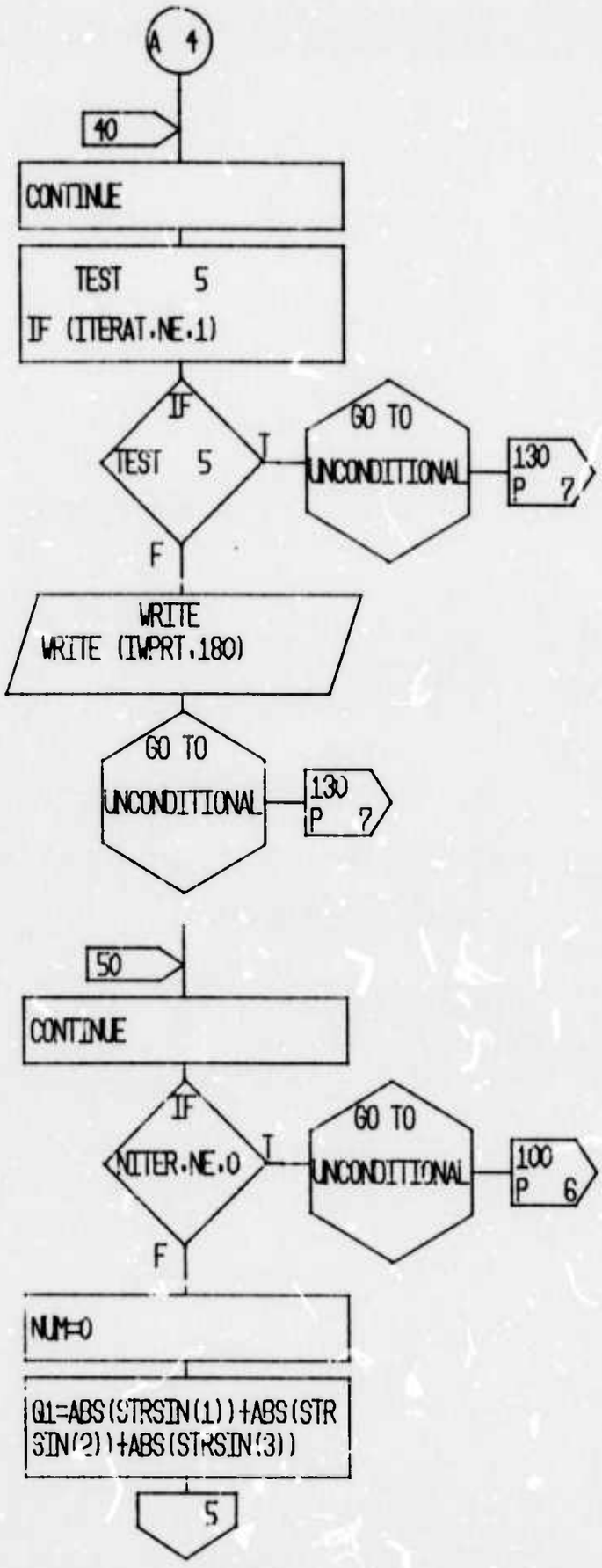

START
C #####
CE 40
C ELPL CONTROLS THE GRO UP OF SUBROUTINES WHICH PRE PARE THE C MATRIX CE 50
C COMPUTE THE STRESSES. . BYPRODUCTS OF THE SE COMP UTATIONS INCLUDE E CE 60
C AND PLASTIC COMPONENT S OF STRAIN, AND MAXIMUM EL ASTIC STRAINS.. EL CE 70
C ALSO CONTROLS ITERATI ON FOR THE APPROPRIATE C AN D STRESSES, AND CO CE 80
C THE CRITERION FOR STR AIN SPLITTING CE 90
C #####
CE 100
COMMON /ELPLS/B,G,RHO,NIS O,NPL,NVISC,NITER,NSTEP,N UMITR,DELTA,CONV,NVM,UMAX ,VMAX,NINTER,GG,NSIZ
COMMON /IWD/IWCD,IWPRT,IW PUNC,IWCOMP,IWSRUN,IWCORE ,IWDEOF,IWBLNK,IWITIN,IWR UN(10),IWNRUN,IWTAPE,IWDR UM,IWLUN(20),IWHDR(20),IW NNP,IWNEL,IWNMAT,IWBAND,I WNEQ,IWNLDB,IWNREC,IWNCF, IWNEQB,IWNEU,IWERR,IWLPPG ,IWKEN,IWDUM(25),LMSTRT,N RSTRT,TIMER,NSTP,MAXSTP,N LDI,NCOL
A 1
A 1
DIMENSION C(6,6),C1(6,6), C2(6,6),CEL(6,6),STRESS(1 2),STROLD(6),STRSIN(6),EP SEL(6),STRINC(6),DEPSEL(6),DEPSPL(6),E(12),F(6),A(6),H(6),GCOF(20),BCOF(40) ,YCOF(25),DIRCOS(3,3),DUM MY(1),STRAIN(12)
C DEFINITION OF INDICIE S
CE 220
C NSIZ= NUMBER OF STRAI N COMPONENTS
CE 230
C NISO(=0 FOR ISOTROP Y) , (=1 FOR ANISOTROPY)
CE 240
C NVISC (=0 IF INVISCID), (=1 IF VISCOPLASTIC), (= 2 IF VISCOELASTIC) CE 250
C NPL (=0 FOR ELASTIC) (=1 FOR INELASTIC) (=2 FOR CAPPED MODEL) CE 260
C NVM (=0 FOR CONSTANT MODULII), (=1 FOR VARIABLE MODULII) CE 270
C NITER (=0 FOR ITERATI ON), (=1 FOR NO ITERATION)
CE 280
C NUMITR = NUMBER OF IT ERATIONS
CE 290
C NELTYP (=1 FOR 1-D ST RESS), (=-1 FOR 1-D STRAIN) , (=2FOR BEAMS) CE 300
2

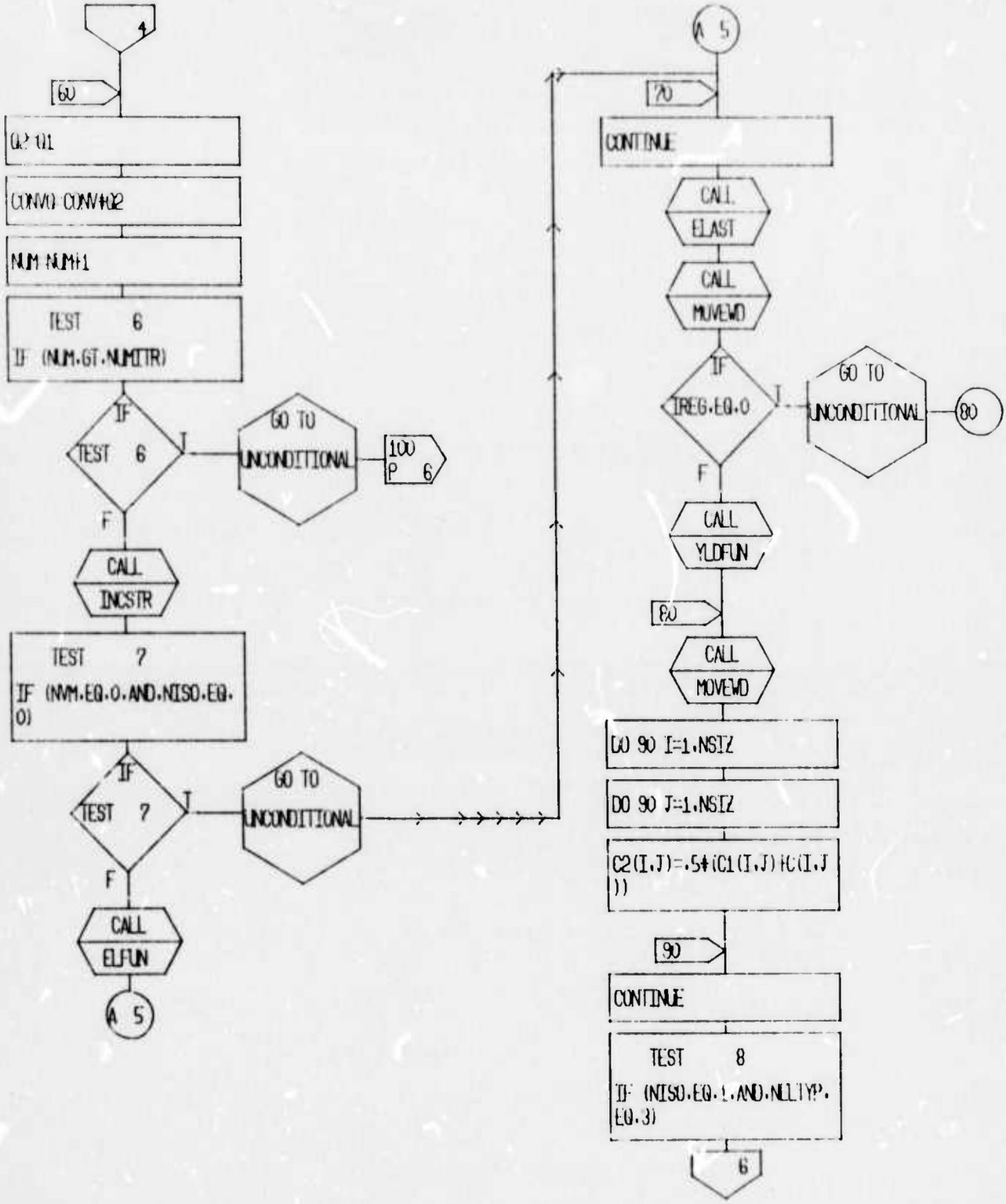

1
C NELTYP (=3 FOR 2-D STRESS), (=-3 FOR 2-D STRAIN), (=6 FOR SHELLS) CE 310
C NELTYP (=4 FOR AXISYM), (=5 FOR 3-D) CE 320
C NELTYP (=7 FOR QUAD SLIP), (=8 FOR 3-D SLIP), CE 330
C NELTYP (=9 FOR AXISYMMETRIC SLIP) CE 340
C CONV = CONVERGENCE CRITERION CE 350
C INITIALIZE CE 370
ALFA=ACOS(DIRCOS(1,1))
FACTOR=0.
IREG=0
JREG=1
CALL SEZERO
CALL SEZERO
CALL MOVEWD
A 2
A 2
TEST 1
IF (NVM.EQ.0.AND.NISO.EQ.0)
IF TEST 1
T
GO TO UNCONDITIONAL
10
F
CALL ELFUN
IF NISO.EQ.2
T
CALL ANISOT
F
10
CONTINUE
CALL ELAST
TEST 2
IF (NISO.EQ.1.AND.NELTYP.EQ.3)
IF TEST 2
T
CALL ANISOT
F
3

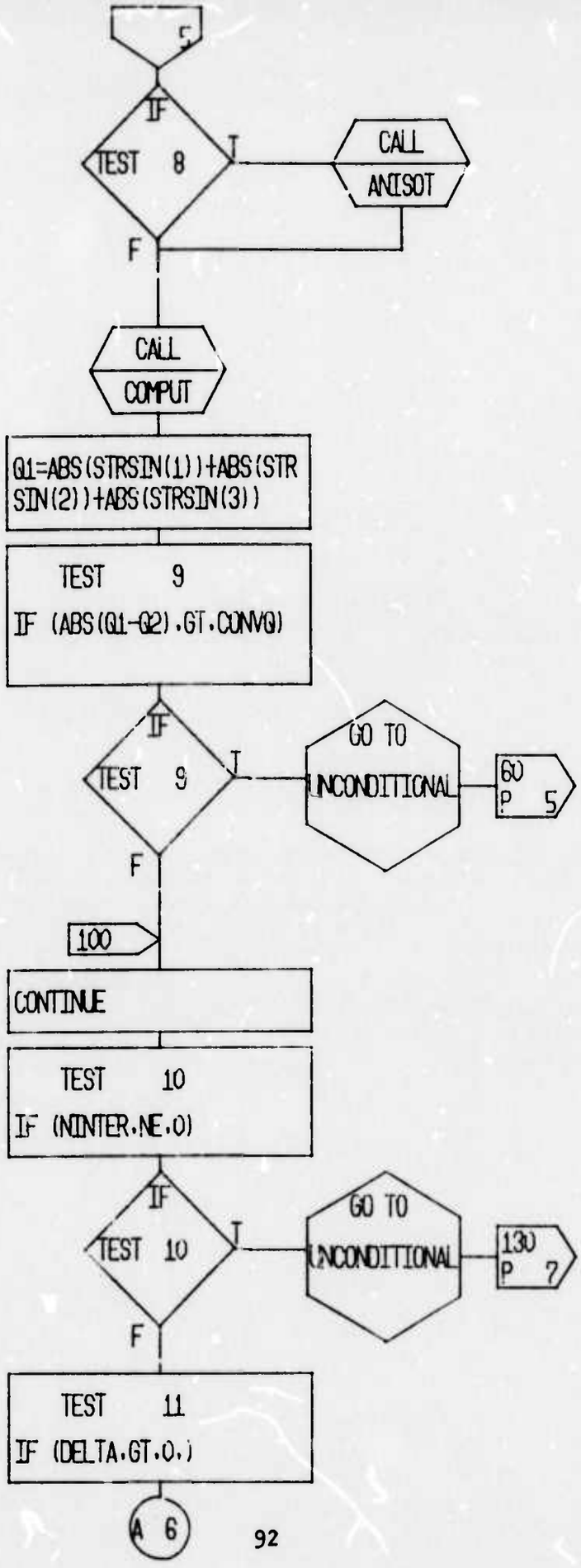

2
IF
NVISC.NE.2
T
CALL
COMPUT
F
CALL
MOVEWD
CALL
MOVEWD
IF
NVISC.EQ.2
T
CALL
VISCEL
F
IF
NVISC.EQ.2
T
GO TO
UNCONDITIONAL
170
P 8
F
IF
NISO.EQ.2
T
GO TO
UNCONDITIONAL
100
P 6
F
IF
NPL.EQ.0
T
GO TO
UNCONDITIONAL
50
P 4
F
CALL
TSTYLD
A 3

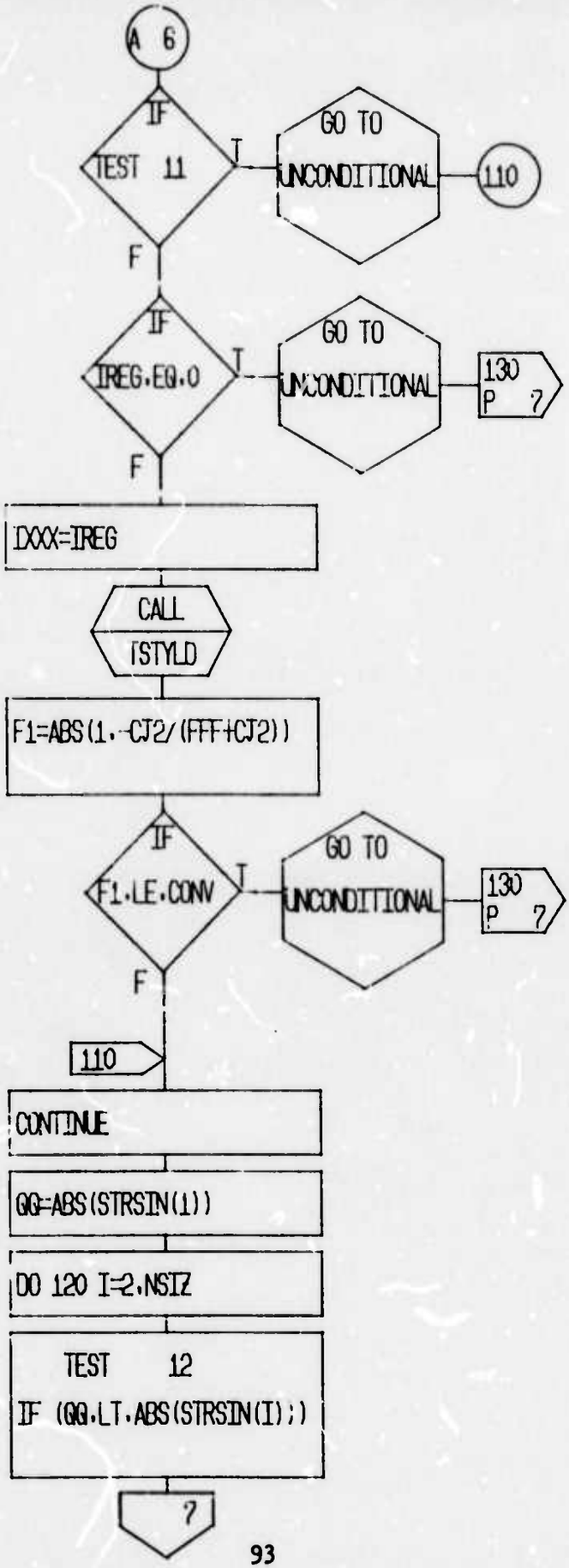

A 3
IF
IREG.EQ.0
T
GO TO
UNCONDITIONAL
50
P 4
F
IF
NVISC.NE.0
T
GO TO
UNCONDITIONAL
20
P 4
F
CALL
MOVEWD
CALL
YLDFUN
TEST 3
IF (NISO.EQ.1.AND.NELTYP.
EQ.3)
IF
TEST 3
T
CALL
ANISOT
F
CALL
COMPUT
GO TO
UNCONDITIONAL
50
P 4
4

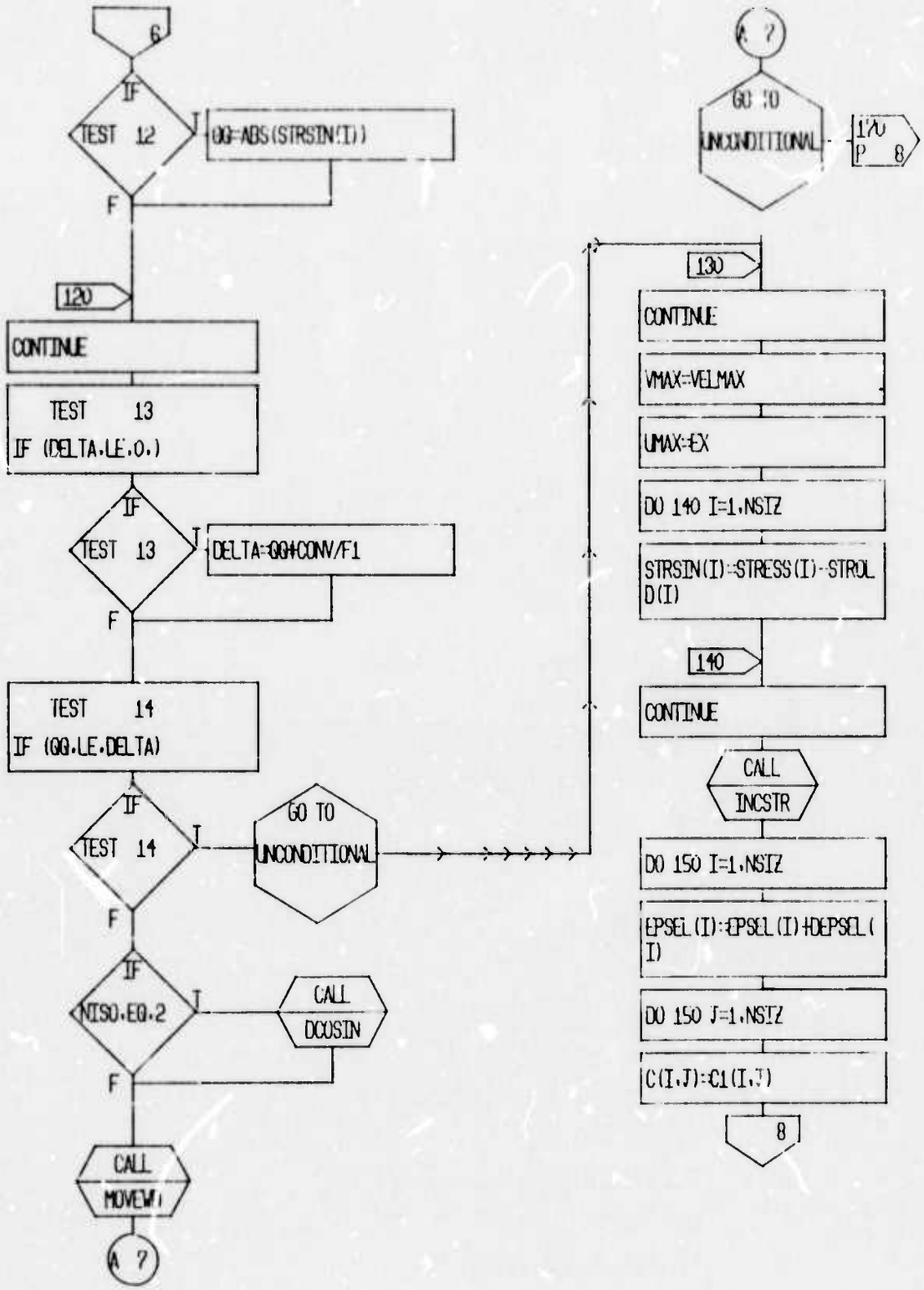

3
20
ITERAT=0
CALL
VPLAST
TEST 4
IF (ITERAT.NE.0)
IF
TEST 4
T
GO TO
UNCONDITIONAL
130
P 7
F
FSTEP=NSTEP
FSTEP=1./FSTEP
DO 30 I=1,NSIZ
STRINC(I)=STRINC(I)*FSTEP
STRESS(I)=STROLD(I)
30
CONTINUE
DO 40 I=1,NSTEP
CALL
COMPUT
CALL
VPLAST
A 4

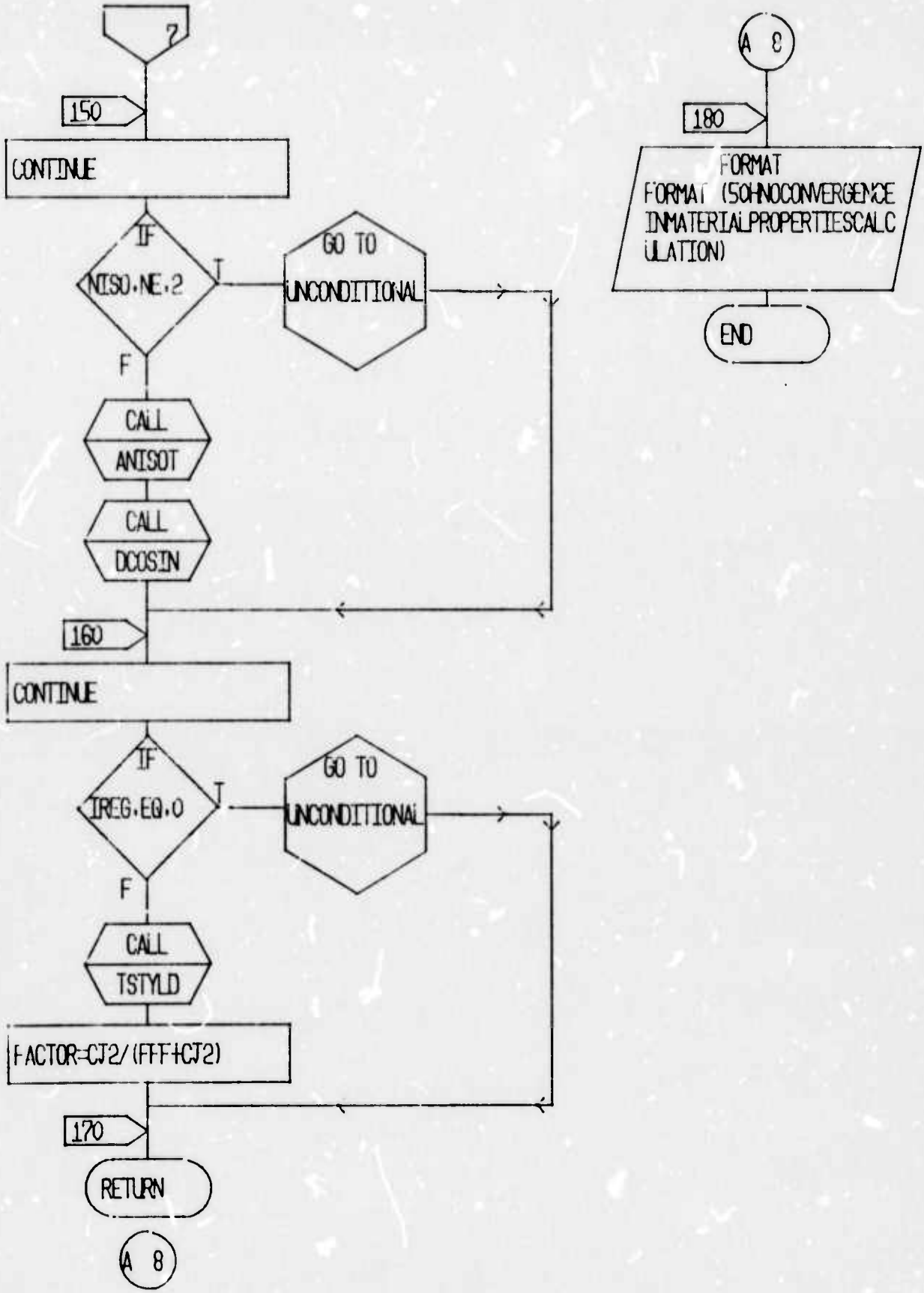

A 4
40
CONTINUE
TEST 5
IF (ITERAT.NE.1)
IF
TEST 5
T
GO TO
UNCONDITIONAL
130
P 7
F
WRITE
WRITE (IWRT,180)
GO TO
UNCONDITIONAL
130
P 7
50
CONTINUE
IF
NITER.NE.0
T
GO TO
UNCONDITIONAL
100
P 6
F
NUM=0
Q1=ABS(STRSIN(1))+ABS(STR
SIN(2))+ABS(STRSIN(3))
5


4
60
Q2 01
CONV() CONV+02
NUM NUM+1
TEST 6
IF (NUM.GT.NUMITR)
IF
TEST 6
T
GO TO
UNCONDITIONAL
100
P 6
F
CALL
INCSTR
TEST 7
IF (NVM.EQ.0.AND.NISO.EQ.
0)
IF
TEST 7
T
GO TO
UNCONDITIONAL
F
CALL
ELFUN
A 5
A 5
70
CONTINUE
CALL
ELAST
CALL
MOVEWD
IF
IREG.EQ.0
T
GO TO
UNCONDITIONAL
80
F
CALL
YLDFUN
80
CALL
MOVEWD
DO 90 I=1,NSIZ
DO 90 J=1,NSIZ
C2(I,J)=.5*(C1(I,J)+C(I,J
))
90
CONTINUE
TEST 8
IF (NISO.EQ.1.AND.NLLTYP.
EQ.3)
6


5
IF
TEST 8
T
CALL
ANISOT
F
CALL
COMPUT
Q1=ABS(STRSIN(1))+ABS(STR
SIN(2))+ABS(STRSIN(3))
TEST 9
IF (ABS(Q1-Q2).GT.CONV0)
IF
TEST 9
T
GO TO
UNCONDITIONAL
60
P 5
F
100
CONTINUE
TEST 10
IF (NINTER.NE.0)
IF
TEST 10
T
GO TO
UNCONDITIONAL
130
P 7
F
TEST 11
IF (DELTA.GT.0.)
A 6


A 6
IF
TEST 11
T
GO TO
UNCONDITIONAL
110
F
IF
IREG.EQ.0
T
GO TO
UNCONDITIONAL
130
P 7
F
IXXX=IREG
CALL
ISTYLD
F1=ABS(1.-CJ2/(FFF+CJ2))
IF
F1.LE.CONV
T
GO TO
UNCONDITIONAL
130
P 7
F
110
CONTINUE
GG=ABS(STRSIN(1))
DO 120 I=2,NSIZ
TEST 12
IF (GG.LT.ABS(STRSIN(I)))
7


6
IF
TEST 12
T
QQ=ABS(STRSIN(I))
F
120
CONTINUE
TEST 13
IF (DELTA.LE.0.)
IF
TEST 13
T
DELTA=QQ*CONV/F1
F
TEST 14
IF (QQ.LE.DELTA)
IF
TEST 14
T
GO TO
UNCONDITIONAL
F
IF
NISO.EQ.2
T
CALL
DCOSIN
F
CALL
MOVEW1
A 7
A 7
GO TO
UNCONDITIONAL
130
130
CONTINUE
VMAX=VELMAX
UMAX=EX
DO 140 I=1,NSIZ
STRSIN(I)=STRESS(I)-STROL
D(I)
140
CONTINUE
CALL
INCSTR
DO 150 I=1,NSIZ
EPSEL(I)=EPSEL(I)+DEPSEL(
I)
DO 150 J=1,NSIZ
C(I,J)=C1(I,J)
8


2
150
CONTINUE
IF
NISO.NE.2
T
GO TO
UNCONDITIONAL
F
CALL
ANISOT
CALL
DCOSIN
160
CONTINUE
IF
IREG.EQ.0
T
GO TO
UNCONDITIONAL
F
CALL
TSTYLD
FACTOR=CT2/(FFF+CT2)
170
RETURN
A 8
A 8
180
FORMAT
FORMAT (50HNOCONVERGENCE
INMATERIALPROPERTIESCALC
ULATION)
END